

THE REARRANGEMENT OF 2,2-DIPHENYL-4-PENTENYL
ALKALI METAL COMPOUNDS

A THESIS

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by
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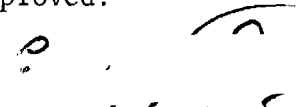
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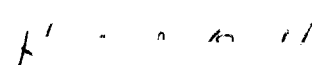
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ALKALI METAL COMPOUNDS

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SUMMARY

The reaction of 5-chloro-4,4-diphenyl-1-pentene with excess lithium metal in tetrahydrofuran (THF) at -75° yields the corresponding unrearranged organolithium compound which was characterized by the acid obtained from carbonation of the solution. Upon warming to -50° rearrangement occurs ($t_{1/2} \approx 30$ min at $-33^{\circ} \pm 2^{\circ}$). The acidic products from this thermal rearrangement correspond to 99% allyl migration and 1% phenyl migration.

Catalyzed rearrangement of the initial organolithium reagent in solution at -75° is observed upon addition of certain basic alkoxide salts. Addition of four equivalents of potassium tert-butoxide per reacted lithium results in complete rearrangement at -75° within less than 10 minutes and yields, after carbonation, acids corresponding to 33% allyl migration and 67% phenyl migration. (The mode of addition of reagents has no effect on the ratio or yield of acid products.) Addition of lithium tert-butoxide has no observable effect while addition of cesium tert-butoxide yields the same acidic products as with potassium tert-butoxide but alters the ratio of rearrangement products somewhat to 25% allyl migration and 75% phenyl migration. Reaction of the starting chloride with potassium metal in refluxing THF yields after carbonation a mixture of acids similar to the potassium tert-butoxide catalyzed reaction (33% allyl migration and 67% phenyl migration).

Specifically labeled starting chloride, 5-chloro-4,4-diphenyl-1-pentene-3- ^{14}C , was prepared starting with allyl-1- ^{14}C alcohol. The

reaction of this chloride with excess lithium metal in THF at -75° with subsequent rearrangement at 0° , -33° , and -50° resulted in allyl migration in which the isotopic label revealed 65% scrambling and 35% "inversion", 45% scrambling and 55% "inversion", and 33% scrambling and 67% "inversion" respectively of the allylic terminus.

Rearrangement of 2,2-diphenyl-4-pentenyl-3- ^{14}C -lithium at -75° by the addition of five equivalents of a 1:1 complex of potassium tert-butoxide:18-crown-6-ether per lithium reacted resulted exclusively in allyl migration in which there was complete "inversion" of the allylic terminus.

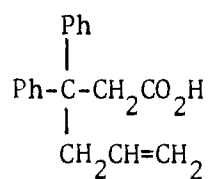
Addition of "hot" allyllithium at -75° to "cold" 2,2-diphenyl-4-pentenyl lithium at -75° with subsequent rearrangement at 0° resulted in 10% ^{14}C -incorporation in the acid from the product of allyl migration.

These results show (1) that organolithium compounds may be prepared in THF and then can be selectively rearranged (thermally or upon addition of alkoxide salts) to give different products dependent upon the reaction conditions, and (2) that the rearrangement of the unsubstituted allyl moiety may occur with "inversion" and/or scrambling of the allylic ^{14}C -terminus. The rearrangement of 2,2-diphenyl-4-pentenyl alkali compounds is believed to occur by mechanisms involving both contact (tight) and solvent-separated (loose) ion pairs to give phenyl and allyl migration respectively. In addition, it has been shown that allyl migration proceeds predominantly in a "solvent-cage" and is believed to occur via competing [3,2]-sigmatropic and elimination-readdition mechanisms.

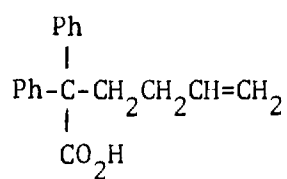
Finally, the reaction of 5-chloro-4,4-diphenyl-1-pentene with magnesium metal at ca. room temperature in THF or in Et_2O gave, after

carbonation, acids corresponding to carbanions of unrearranged carbon skeleton or of phenyl migration respectively.

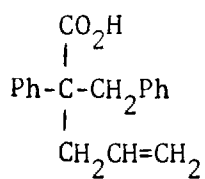
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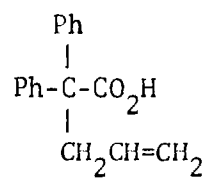
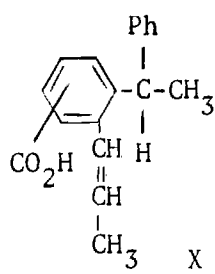
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Internal Standard

CHAPTER I

INTRODUCTION

Molecular rearrangements,¹ whether from a neutral or charged intermediate are directly related to man's understanding of the structure and reactivity of matter. They are generally classified according to (1) class of compound, (2) reactive intermediate, (3) method of initiation, or (4) reaction mechanism. Several types of intermediates are postulated² among which is the rearrangement of carbanion or carbanionoid (ylid) systems.³ Each of these systems as a general rule, must be assumed, at this time, to react in a unique way^{1a} depending on the reaction conditions.⁴

Carbanionic (carbanionoid) molecular rearrangements have been

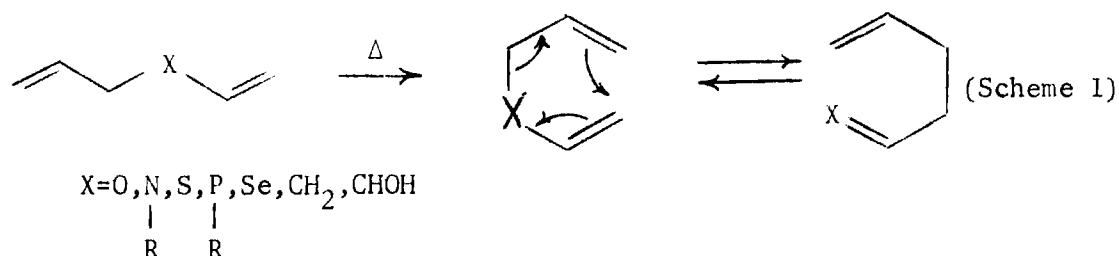
1. (a) T. S. Stevens and W. E. Watts, Selected Molecular Rearrangements, Van Nostrand Reinhold Co., New York, NY, 1973; (b) P. de Mayo, Ed., Molecular Rearrangements, Vol. 1 & 2, Interscience, New York, NY, 1963; (c) B. S. Thyagarajan, Ed., Mechanisms of Molecular Rearrangements, Vol. 1-3, 1971; (d) H. J. Shine, Aromatic Rearrangements, Elsevier, Amsterdam, 1967; (e) S. Pine, Organic Reactions, 18, 403 (1975).

2. S. P. McManus, Ed., Organic Reactive Intermediates, Academic Press, New York, NY, 1973.

3. U. Schollkopf, Angew. Chem., Internat. Edit. Engl., 9, 763 (1970).

4. (a) A. R. Lepley and R. H. Becker, Tetrahedron, 21, 2365 (1965); (b) R. W. Jemison, T. Laird, and W. D. Ollis, J. Chem. Soc., Chem. Commun., 556 (1972); (c) T. Laird and W. D. Ollis, J. Chem. Soc., Chem. Commun., 557 (1972); (d) W. D. Ollis, R. Somanathan, I. O. Sutherland, J. Chem. Soc., Chem. Commun., 494 (1974).

reported in increasing frequency and are not as rare as once thought.^{3,5} On the other hand, allylic migration is one of the most widely known and studied processes in nature. The majority of the work concerning allyl migration resulted from the discovery by Claisen that allyl vinyl ether rearranged thermally to give a homoallyl carbonyl compound⁶ (Scheme I).



Subsequent work in which the vinyl group was incorporated into an aromatic ring provided even greater possibilities of synthetic utility.⁷ The general concept of the Claisen rearrangement was extended by introduction of the heteroatoms N, S, P, and Se.⁸ Replacement of the heteroatom with a methylene/hydroxy-methylene group likewise resulted in

5. D. J. Cram, Fundamentals of Carbanion Chemistry, Academic Press, New York, NY, 1965.

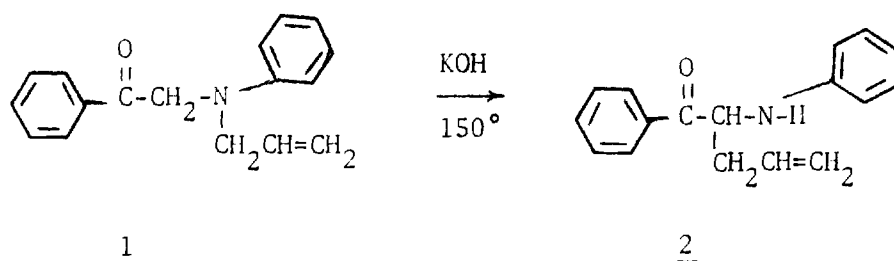
6. L. Claisen, Ber., 45, 3157 (1912).

7. (a) D. S. Tarbell, Organic Reactions, Vol. II, R. Adams, Ed., Wiley, New York, NY, 1944; (b) S. B. Thyagarajan, Advan. Heterocyclic Chem., 8, 143 (1967); (c) W. C. McDaniel, Organic Division Seminar, Georgia Institute of Technology, April 25, 1974.

8. (a) A. Jefferson and F. Scheinmann, Quarterly Reviews, 22, 391 (1968); (b) R. K. Hill and N. W. Gilman, Tetrahedron Lett., 1421 (1967); (c) J. Fincini and C. Barbara, Tetrahedron Lett., 6425 (1966); (d) H. Kwart and H. M. Cohen, J. Org. Chem., 32, 3135 (1967); (e) A. W. Herriott and K. Mislow, Tetrahedron Lett., 3013 (1968); (f) E. G. Kataev, G. A. Chmutova, A. A. Musina, and A. P. Anatos'eva, Zh. Org. Khim., 3, 597 (1967); (g) M. Schmid, H. J. Hansen, H. Schmid, Helv. Chim. Acta, 56, 105 (1973).

rearrangement (Cope/oxy-Cope).⁹ These intramolecular thermal rearrangements were essentially insensitive to solvent effects and were referred^{8a} to as proceeding via a "no mechanism" pathway. However, the highly stereospecific nature of the rearrangements (inversion of allyl) via a preferred six-centered quasi-chair transition state has been generally accepted to proceed, in part if not in total, by an allowed [3,3]-sigmatropic rearrangement, consistent with the theory of Woodward and Hoffman concerning the conservation of orbital symmetry.^{10,11}

For the base catalyzed thermolysis of tertiary amines Stevens *et al.*¹² found that allyl and benzyl migrated in preference to phenyl and that these rearrangements were intramolecular.



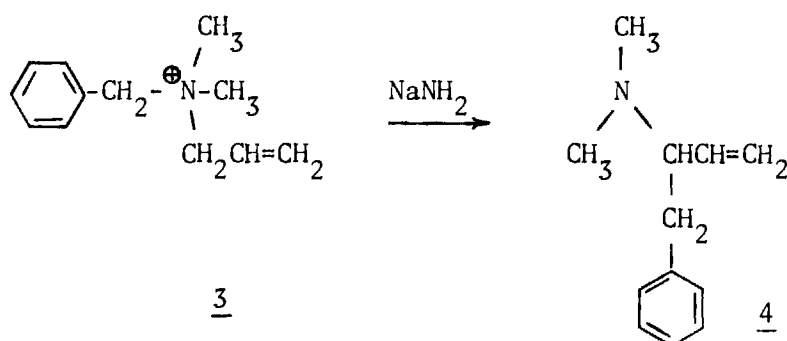
9. (a) A. C. Cope and E. M. Hardy, *J. Amer. Chem. Soc.*, **62**, 441 (1940); (b) J. A. Berson and M. Jones, *J. Amer. Chem. Soc.*, **86**, 5017, 5019 (1964).

10. "The choice of solvent has often been underestimated: from our experience a tertiary aromatic amine such as N,N-diethyl- or N,N-dimethylaniline has proved to be a most versatile solvent for aromatic Claisen rearrangements" (cf. 8a, p. 419).

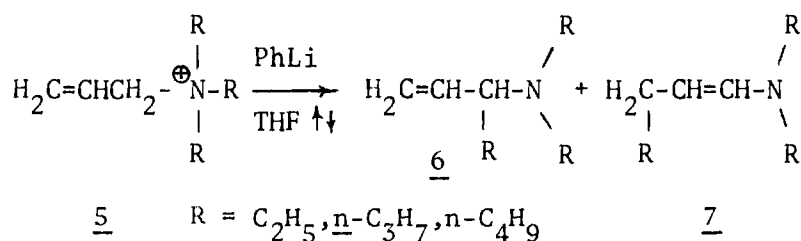
11. R. B. Woodward and R. Hoffmann, *The Conservation of Orbital Symmetry*, Academic Press, Weinheim, Germany, 1971.

12. (a) R. A. W. Johnstone and T. S. Stevens, *J. Chem. Soc.*, 4487 (1955); (b) W. F. Cockburn, R. A. W. Johnstone, and T. S. Stevens, *J. Chem. Soc.*, 3340 (1960); (c) R. A. W. Johnstone and T. S. Stevens, *J. Chem. Soc.*, 3346 (1960).

Stevens also found that appropriately substituted quaternary ammonium salts rearrange intramolecularly but that benzyl migrated rather than did allyl under the influence of strong base.¹³



Analogously, Hellman and Scheytt¹⁴ found that alkyl groups migrated 1,2 and 1,4 to the termini of the delocalized allyl group when the triethylallyl ammonium salt, 5, was refluxed with phenyllithium.



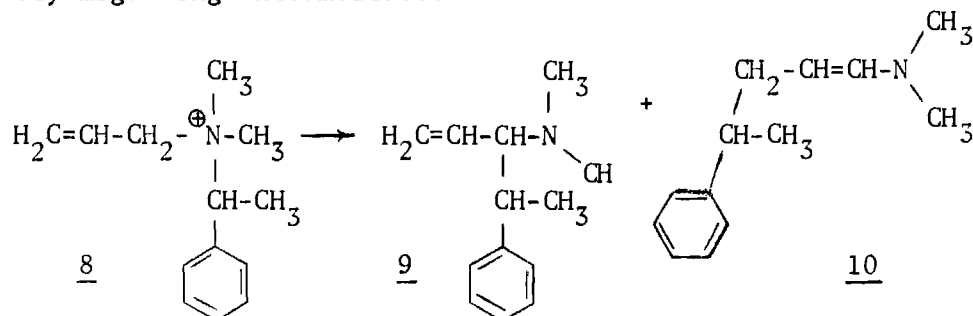
Jenny and Druey¹⁵ treated optically active allyl-1-phenethyl-dimethylammonium bromide, 8, with sodium amide in benzene (80°) and liquid ammonia (-33°) and found 1,2 and 1,4 migration of benzyl. The benzyl group migrated 1,2 with at least 90% retention of configuration

13. T. Thomson and T. S. Stevens, J. Chem. Soc., 1932 (1932).

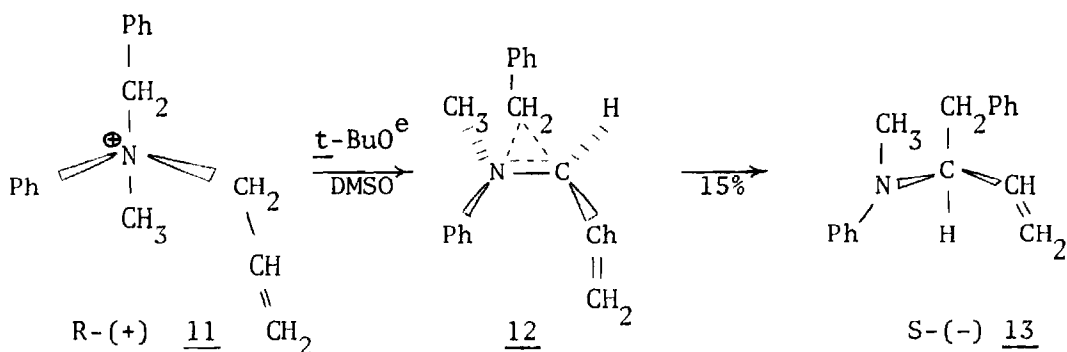
14. H. Hellman and G. M. Scheytt, Liebigs Ann. Chem., 643, 39 (1962).

15. E. F. Jenny and J. Druey, Angew. Chem., Internat. Edit. Engl., 1, 155 (1962).

and 1,4 with $82 \pm 10\%$ (benzene) and $72 \pm 10\%$ (ammonia) retention of configuration. It was therefore assumed that the "benzyl anion" was the likely migrating intermediate.^{5,15}



In like manner, 1,2-migration of benzyl and transfer of "centro-dissymmetry" was observed by Hill and Chan¹⁷ when the R-(+)-allylbenzyl-methylphenylammonium salt, **11**, was treated with *tert*-butoxide in dimethylsulfoxide to give a low yield (15%) of S-(-)-1-(benzyl)-allylmethylphenyl tertiary amine.



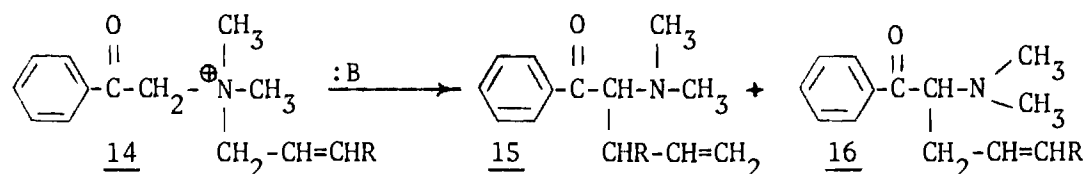
Stevens and Millard¹⁸ compared the rates, migratory aptitude, and distribution of products of allylic rearrangement for the

16. M. J. S. Dewar and J. Milton, *J. Amer. Chem. Soc.*, **91**, 3652 (1969).

17. R. K. Hill and T. H. Chan, *J. Amer. Chem. Soc.*, **88**, 866 (1966).

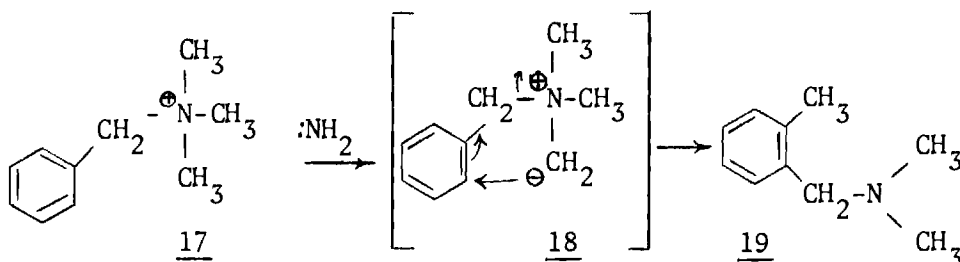
18. B. J. Millard and T. S. Stevens, *J. Chem. Soc.*, 3397 (1963).

appropriately substituted allyldimethylphenacylammonium salts, 14, upon treatment with base. It was found that the migratory aptitude was $\text{Ph-CH=CH-CH}_2^- > \text{CH}_2=\text{CH-CH}_2^- > \text{Ph-CH}_2^-$ and the relative migratory rates were 90,000:500:1, respectively. This result suggests that more than one mechanism is operative since the ratio of the products of allylic "inversion" to "retention" varies, depending on the substituent (phenyl vs methyl).



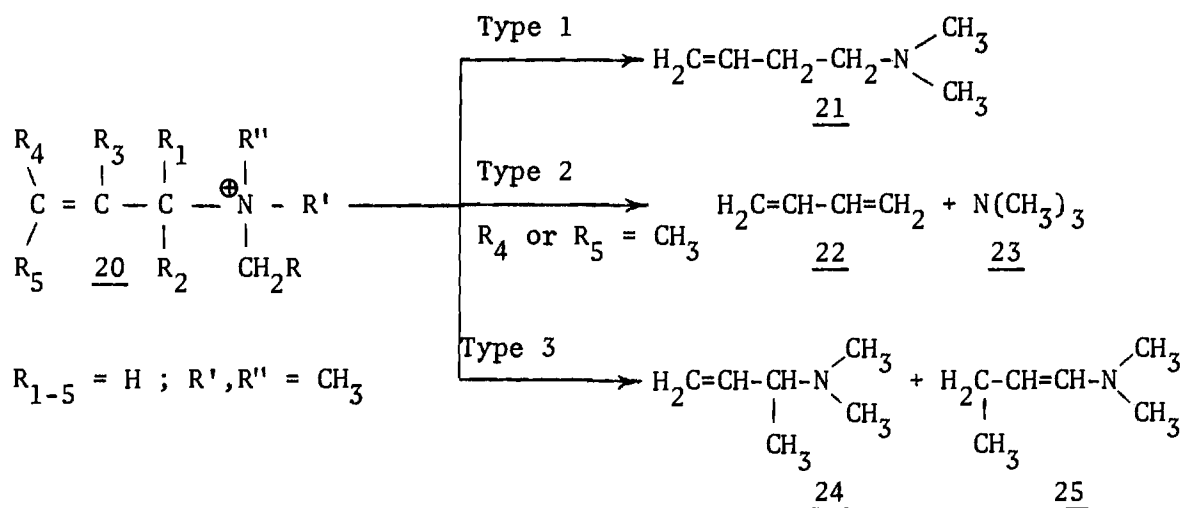
R-	% 15	% 16
Phenyl	55	45
Methyl	100	--

The report by Kantor and Hauser¹⁹ that benzyltrimethylammonium salts, 17, rearranged on treatment with sodium amide to give o-methylbenzyl-N,N-dimethylamine prompted a systematic study of the action of sodium amide on allyl quaternary ammonium salts.



19. (a) S. W. Kantor and C. R. Hauser, J. Amer. Chem. Soc., **73**, 1437, 4122 (1951); (b) A. R. Lepley and R. H. Becker, J. Org. Chem., **30**, 3888 (1965).

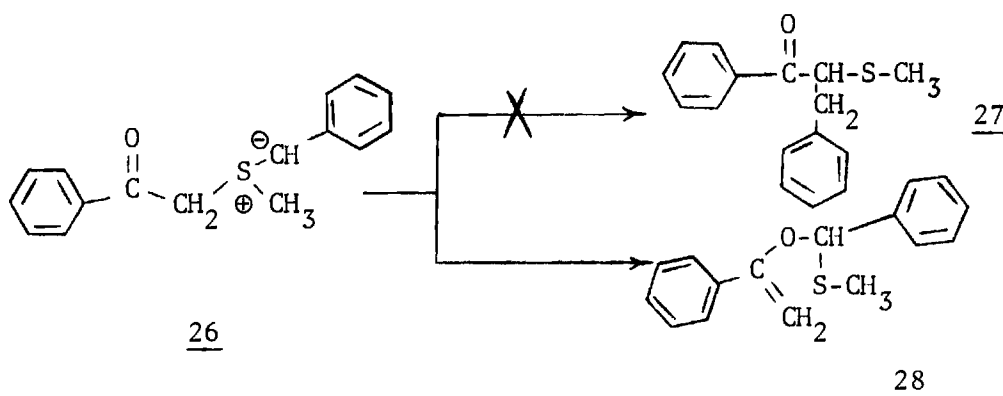
Paul and Tshelitcheff²⁰ reported that three (3) distinct types of reactions were operative simultaneously with the relative paths being dependent on the nature of the substituents on the allyl moiety.



Alkyl substitution at R_1 , R_2 , and R_3 favored reaction type 1 and demonstrated that the transition state for allylic migration was 5-centered rather than 3-centered and proceeded with "inversion" of the allylic carbons. Substitution of at least one ethyl group on the nitrogen (rather than methyl) resulted in allylic deprotonation with 1,2 and 1,4 migration of the ethyl group as had been shown earlier. Alkyl substitution of R_4 and/or R_5 resulted in hydrogen migration with elimination of a conjugated diene (facilitated by cis geometry) and the corresponding tertiary amine. Aryl substitution of R_4 (cis) gave an allylic anion with migration of an alkyl group (methyl or ethyl, depending on the specific ammonium salt) and thus apparently proceeded via a different mechanism than that of the compound from alkyl substitution.

20. R. Paul and S. Tchelitcheff, Bull. Soc. Chim. Fr., 1289 (1967).

Stevens²¹ reported the base-catalyzed rearrangement of sulphonium salt, 26, to the sulfide, 27, but reinvestigation by Ruiz and Ratts^{22,23} proved the major product was, 28, which resulted from an analogous heteroatom allylic rearrangement of an ylid rather than a product of benzylic rearrangement.



Lepley²⁴ observed "chemically induced dynamic nuclear polarization"²⁵ (CIDNP) during the benzyl migration of the quaternary ammonium intermediate, 31. He proposed the general postulation that in Stevens rearrangements the migrating group underwent a homolytic bond cleavage during the 1,2-shift from nitrogen to carbon in a "radical-pair cage" and then collapsed to give the observed product.

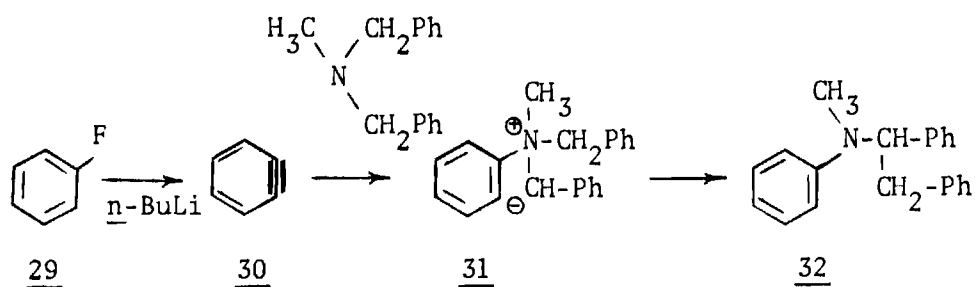
21. T. Thomson and T. S. Stevens, J. Chem. Soc., 69 (1932).

22. (a) E. B. Ruiz, Acta Salmenticensi, Ser. Ciencia, 2, 64 (1958) [Chem. Abstr., 54, 7623 (1960)]; (b) K. W. Ratts and A. N. Yao, Chem. Ind. (London), 1963 (1966).

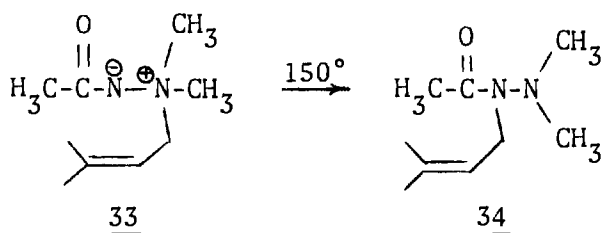
23. U. Schollkopf, J. Schossig, and O. Ostermann, Ann. Chem., 737, 158 (1970).

24. A. R. Lepley, Chem. Commun., 1460 (1969).

25. (a) H. R. Ward, Accts. of Chem. Res., 5, 18 (1972); (b) R. G. Lawler, Accts. of Chem. Res., 5, 25 (1972).



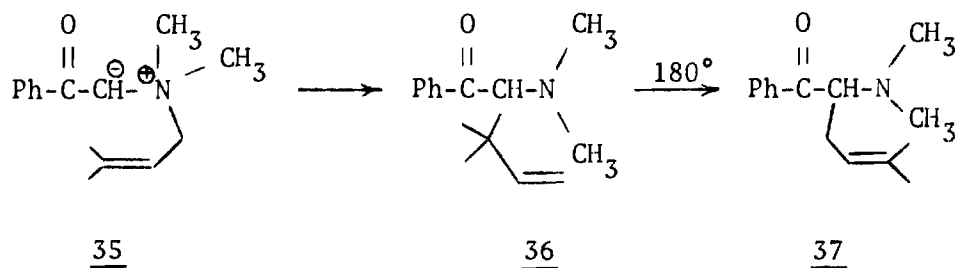
Morris²⁶ found CIDNP for the allylic methylene protons in the thermolysis of N-allylamido-ammonium salts, 33, and likewise suggested that a "radical-pair" was formed which collapsed to the observed product with no "inversion" of the allylic moiety.



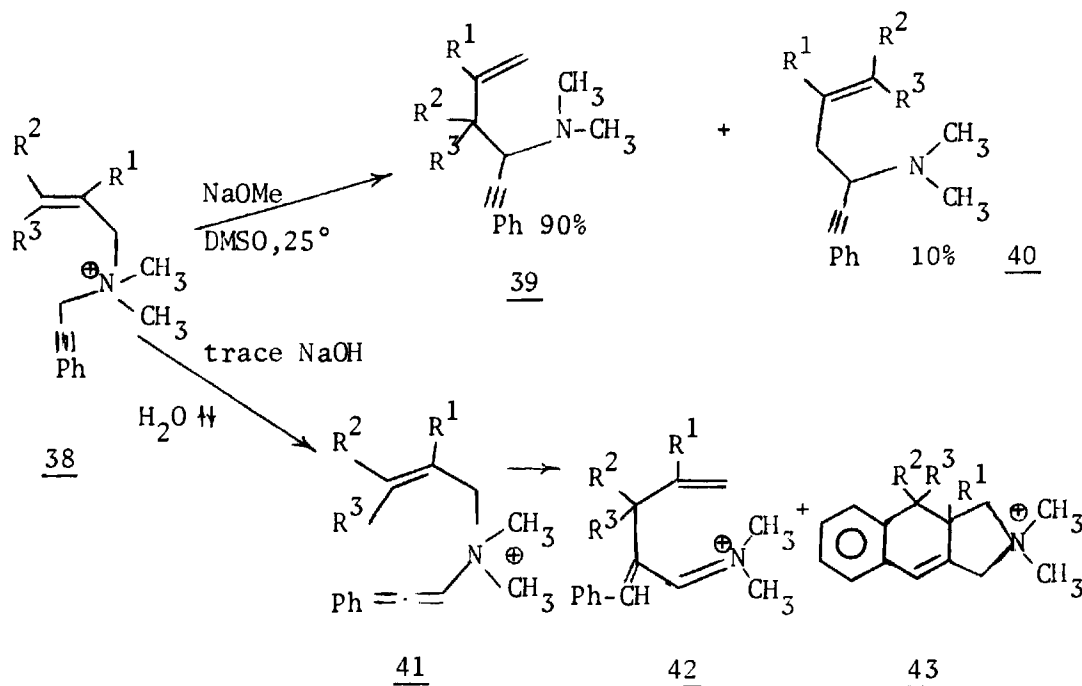
However, in keeping with the initial mechanistic pattern of similar allylic rearrangements, it was subsequently proposed that an intermediate was formed (presumably by a concerted pathway) which then underwent homolytic cleavage to form the thermodynamically more stable allylic isomer with "net retention" at the allylic terminus, similar to that observed by Ollis and Gibson.²⁷

26. D. G. Morris, Chem. Commun., 1345 (1965).

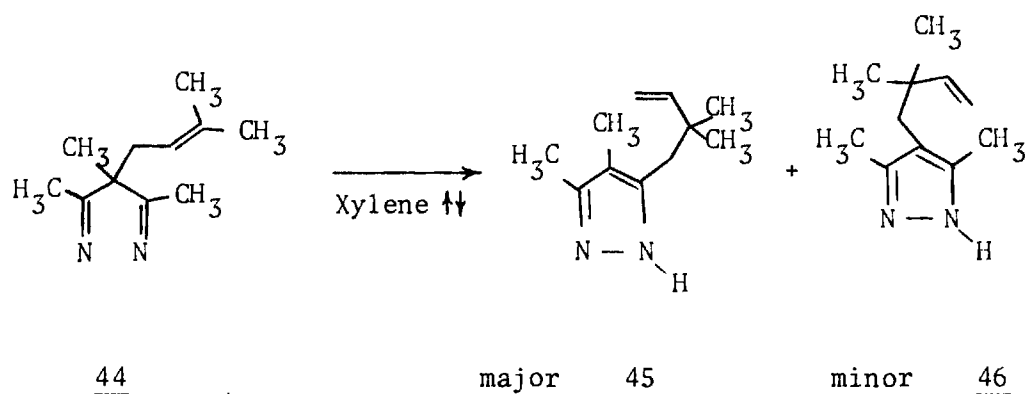
27. (a) R. W. Jemison and W. D. Ollis, Chem. Commun., 294 (1969); (b) J. E. Baldwin, J. E. Brown, and R. W. Cordell, Chem. Commun., 31, (1970); (c) I. D. Brindle and M. S. Gibson, Chem. Commun., 803 (1969).



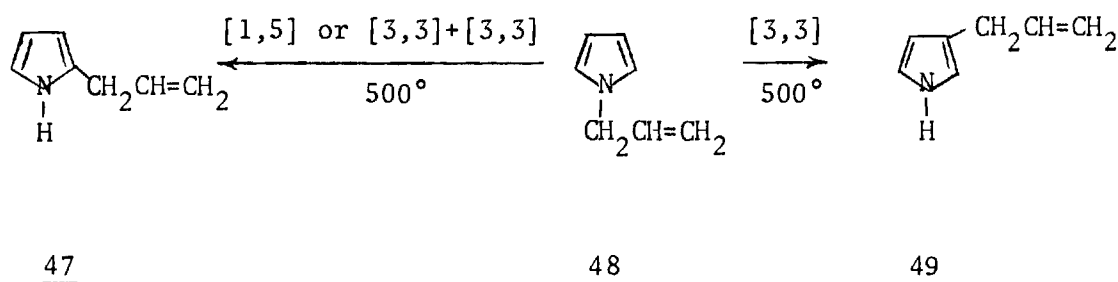
Treatment of allylpropynylammonium salt, 38, with sodium methoxide in dimethylsulfoxide by Ollis^{4b,c} gave two products which were apparently formed via a concerted [2,3]-sigmatropic and a radical-pair intermediate to give, 39 and 40, respectively. However, treatment of salt, 38, with a trace of sodium hydroxide in water gave very different products. It was proposed that the ammonium salt, 38, common in both reaction systems isomerized to, 41, which could then undergo a [3,3]-sigmatropic rearrangement or undergo a $[4\pi + 2\pi]$ -cycloaddition reaction. This observation by Ollis and coworkers certainly illustrates the complexity of mechanisms that one may encounter.



Grigg and coworkers²⁸ found that the dimethyl isopyrazole, 44, rearranged via a [3,3]-sigmatropic rearrangement to give the product of allylic inversion as well as the product of either a [1,3]-sigmatropic rearrangement or a radical-pair dissociation-readdition mechanism.



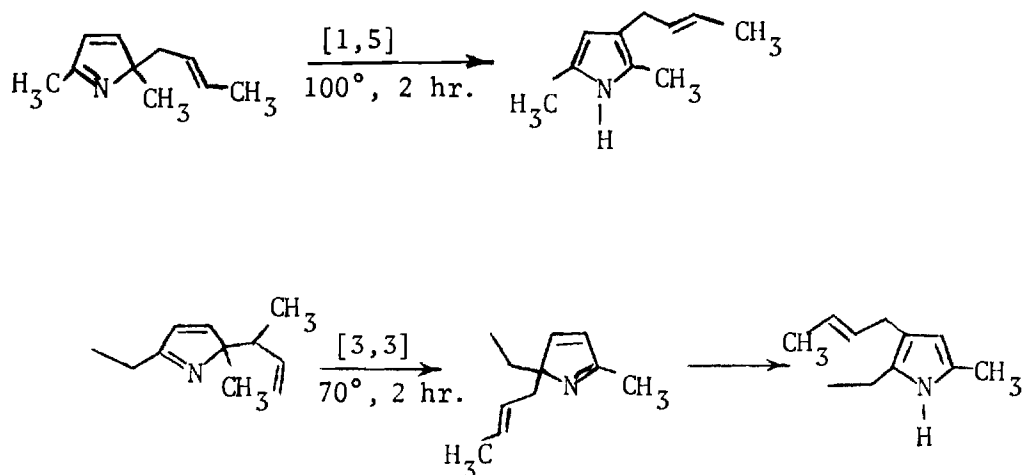
The problem of competing mechanisms was further investigated by Patterson and coworkers²⁹ in that N-allyl pyrroles underwent competitive [1,5]- and [3,3]-sigmatropic rearrangements in the "gas phase."



28. R. K. Bramley, R. Grigg, G. Guilford, and P. Milner, Tetrahedron, 29, 4159 (1973).

29. J. M. Patterson, J. W. deHaan, M. R. Boyd, and J. D. Ferry, J. Amer. Chem. Soc., 94, 2487 (1972).

Their work also showed³⁰ that the thermal rearrangement of substituted allyldialkyl-2H-pyrroles proceeded in a similar manner but the sigmatropic migration mechanism was dependent on the substitution of the allyl moiety. The crotyl derivative, 50, migrated [1,5] without inversion from the 2- to the 3-position of the ring but the 1-methyl allyl group, 52, migrated [3,3] to position 4 (minor) or 5 (major) of the ring with inversion. Of the two competing mechanisms, the [3,3]-sigmatropic path had the faster rate.

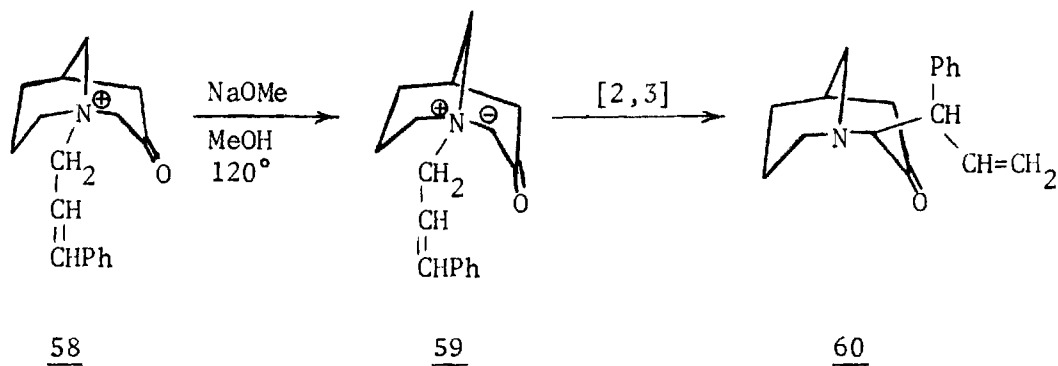
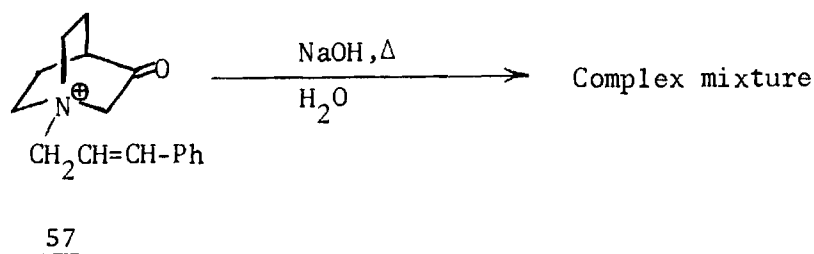
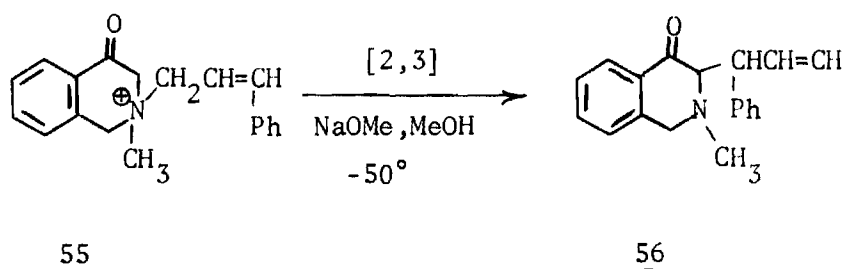


Ollis³¹ found that the transition-state geometry was important in allylic [2,3]-sigmatropic rearrangements of ammonium ylides. He reported that the N-cinnamylisoquinolinium derivative, 55, rearranged rapidly whereas the ylide obtained on treatment of N-cinnamyl-1-azabicyclo[2,2,2]-octan-3-oneammonium bromide, 57, did not rearrange

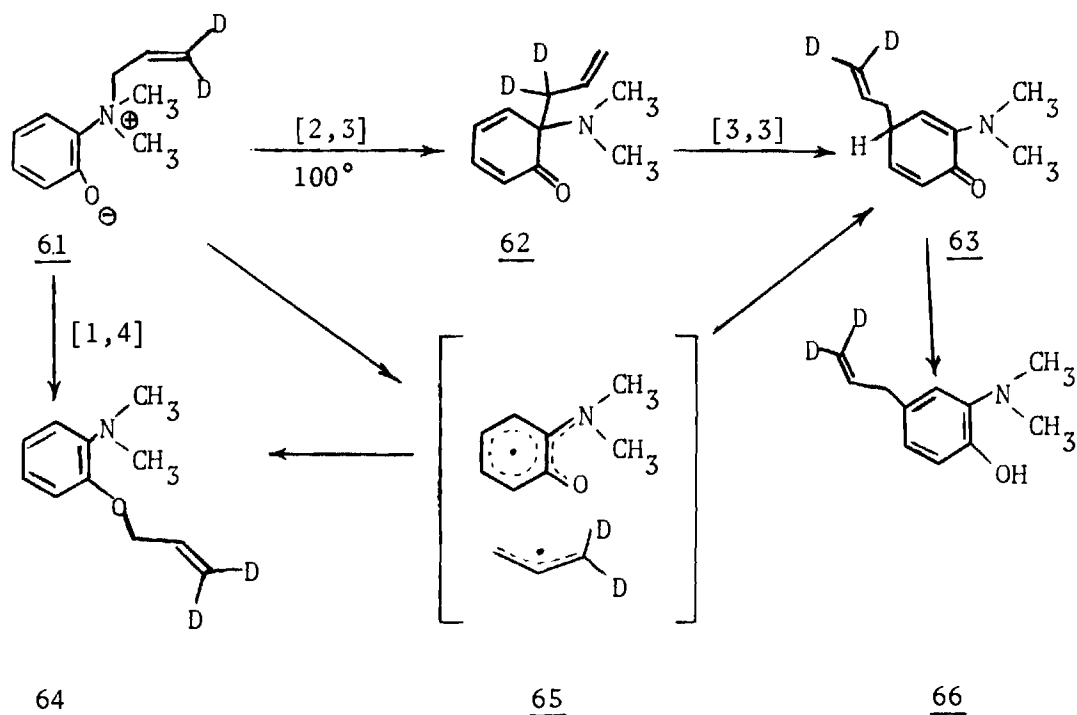
30. J. M. Patterson, J. D. Ferry, J. W. deHaan, and M. R. Boyd, J. Amer. Chem. Soc., **97**, 360 (1975).

31. S. Mageswaran, W. D. Ollis, I. O. Sutherland, and Y. Thebtaranonth, Chem. Commun., 1494 (1971).

cleanly. However, the ylide, 59, of the N-cinnamyl-1-azabicyclo[3,3,1]nonan-3-oneammonium salt, 58, rearranged smoothly at 120° to give a good (85%) yield of, 60, the product of allylic inversion. Thus, the torsional strain involved in obtaining the required geometry in the transition-state is apparently important in determining whether a low energy sigmatropic pathway is allowed or a competing higher energy alternative mechanism is required.



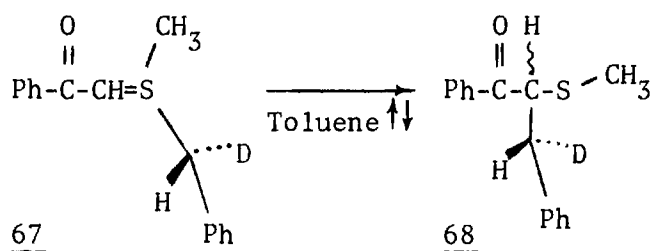
Competitive mechanisms were again shown operative by Sutherland³² in the rearrangement of the N-allyl betaine, 61. It was shown by deuterium labeling experiments that the rearrangement proceeded with a minor contribution of a [1,4]-sigmatropic rearrangement whereas the major paths involved a dissociation-recombination of a radical-pair* (36%) and a consecutive [2,3]- and [3,3]-sigmatropic rearrangement (64%).



32. I. O. Sutherland, Chem. Brit., 9, 362 (1973).

*The danger of relying only on CIDNP studies in expressing opinions regarding reaction mechanism was noted by Sutherland.

An approximation of the relative importance of the "radical-pair cage" mechanism was given by Baldwin³³ who reported observation of CIDNP for the rearrangement of sulphonium ylid, 67, and showed that only 12% of the radicals escaped the "radical-pair cage" while 36% of the optional activity of the migrating benzyl group was retained.



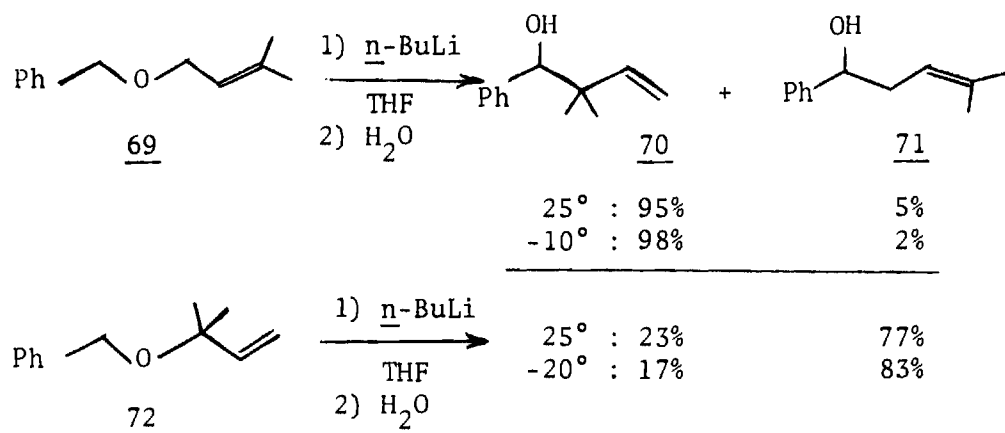
He proposed that the rearrangement of sulfonium ylides may undergo two competing mechanistic paths; (1) a concerted rearrangement with conservation of orbital symmetry and (2) a non-concerted radical dissociation-recombination process,³⁴ rather than an S_Ni mechanism.

Baldwin³⁵ also reported that a duality of mechanism was observed in the base catalyzed Wittig rearrangement of allylbenzyl ethers, 69, and, 72, as was evidenced by a temperature dependent distribution of products.

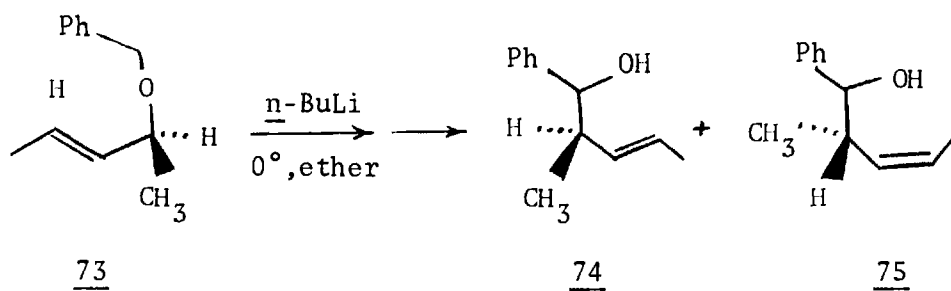
33. J. E. Baldwin, W. F. Erickson, R. E. Hackler, and R. M. Scott, Chem. Commun., 576 (1970).

34. (a) J. E. Baldwin, R. W. Hackler, and D. P. Kelly, Chem. Commun., 537, 538, 1083 (1968); (b) J. E. Baldwin, R. W. Hackler, and D. P. Kelly, J. Amer. Chem. Soc., 90, 4758 (1968); (c) J. E. Baldwin and R. E. Hackler, J. Amer. Chem. Soc., 91, 3646 (1969); (d) V. Rautenstrauch, Helvetica Chimica Acta, 55, 2233 (1972).

35. J. E. Baldwin, J. De Bernardis, and J. E. Patrick, Tetrahedron Lett., 353 (1970).



Additional work³⁶ has shown that treatment of the chiral ether, 73, by base at 0° gave the Wittig product via 28% of the "escaped" radical pathway with the remainder by a [2,3]-sigmatropic process while treatment at -80° gave complete domination of the concerted process. Taking into consideration the geometry and symmetry involved, it was concluded that the concerted process proceeded via a 5-centered doubly suprafacial transition state.

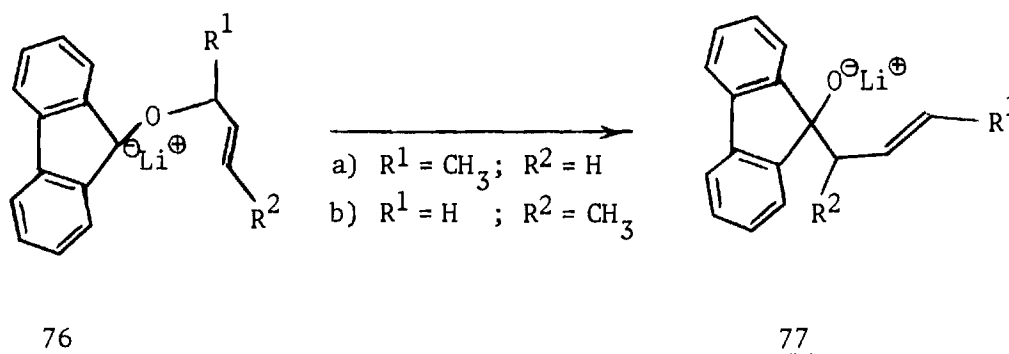


Schollkopf and Fellenberger³⁷ found that 9-lithio-9-fluorenyl-

36. J. E. Baldwin and J. E. Patrick, J. Amer. Chem. Soc., 93, 3556 (1971).

37. (a) U. Schollkopf and K. Fellenberger, Liebigs Ann. Chem.,

1-methylallyl ether and its allylic isomer spontaneously rearranged at -50° to -60° to give lithium-9-trans-crotylfluorenolate and lithium-9-(1-methylallyl)-fluorenolate, respectively.

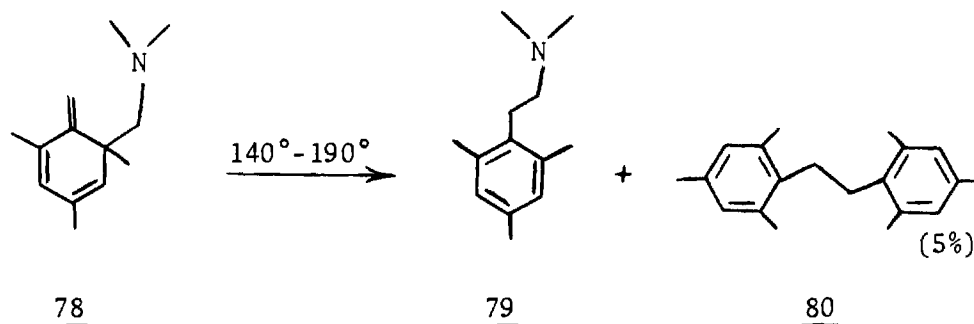


Hauser and Van Eenam³⁸ found the exo-methylenecyclohexadienamine, 78, rearranged thermally to 79. This rearrangement was shown to be unimolecular, proceeded readily under homogeneous conditions, exhibited a CIDNP³⁹ effect for the benzylic protons of the product 79 and was postulated to proceed by a "radical-pair" dissociation-recombination mechanism rather than a thermal [1,3]-sigmatropic process.

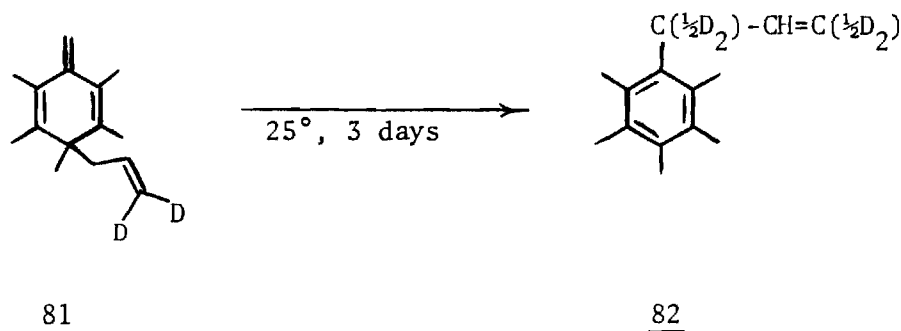
698, 80 (1966); (b) K. Fellenberger, Diplomarbeit, Universitat Heidelberg, Heidelberg, Germany (1964); (c) Y. Makisumi and S. Notzumoto, Tetrahedron Lett., 6393 (1966).

38. C. R. Hauser and D. N. Van Eenam, J. Amer. Chem. Soc., 79, 5512, 5520, 6274, 6277 (1957).

39. J. E. Baldwin and J. E. Brown, J. Amer. Chem. Soc., 91, 3647 (1969).



Analogously, Miller reported⁴⁰ that allylic migration in the semibenzene rearrangement apparently proceeded by a free-radical chain mechanism since the deuterated compound was equilibrated and the reaction was affected by the presence of radical chain inhibitors and initiators.



As a general rule of thumb, most allylic rearrangements, whether anionic or not, have been observed with systems which contain one or more heteroatoms. This observation may be due to the fact that the system is essentially perturbed and thus favors electrocyclic electron flow to form the thermodynamically more stable isomer.⁴¹ Thus, it

40. B. Miller and K. H. Lai, J. Amer. Chem. Soc., 94, 3472 (1972).

41. Recent studies have shown the thermal concerted rearrangement

would seem observations of rearrangement in an all carbon system would tend to allow the more fundamental problems regarding molecular stability to be studied and applied.

Just such an observation was made by Grovenstein⁴² and Zimmerman⁴³ when it was found phenyl migrated in the rearrangement of 2,2,2-triphenylethylsodium and that the ease of rearrangement of the carbanion with corresponding lithium or potassium gegenion paralleled the degree of ionic character of the carbon-metal bond.⁴⁴ The migratory aptitude of benzyl was shown to be greater than that of phenyl⁴⁵ while ¹⁴C-tracer studies by Grovenstein and Wentworth⁴⁶ with external "hot" phenyl- and benzyl lithium indicated phenyl and benzyl migrated via intra- and intermolecular pathways respectively.

of the oxy- and thio-Claisen rearrangements to be catalyzed by electrophilic and nucleophilic reagents, respectively. H. Kwart and J. L. Schwartz, J. Org. Chem., **39**, 1575 (1974). In addition, mercuric ion catalysis of the thermal [3,3]-sigmatropic rearrangement of allylic trichloroacetimidates has been reported by L. E. Overman, J. Amer. Chem. Soc., **96**, 597 (1974).

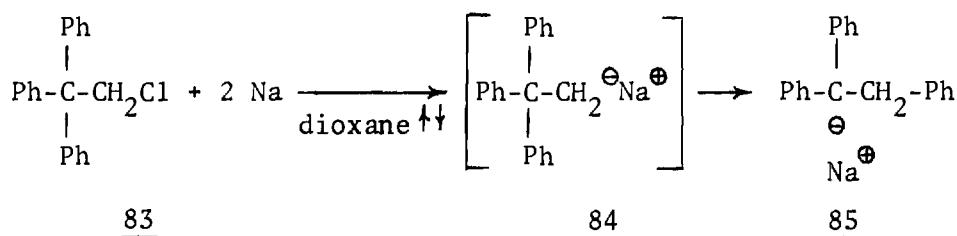
42. E. Grovenstein, Jr., J. Amer. Chem. Soc., **79**, 4985 (1957).

43. H. E. Zimmerman and F. J. Smentowski, J. Amer. Chem. Soc., **79**, 5455 (1957).

44. E. Grovenstein, Jr. and L. P. Williams, J. Amer. Chem. Soc., **83**, 412 (1961).

45. E. Grovenstein, Jr. and L. P. Williams, J. Amer. Chem. Soc., **83**, 2537 (1961).

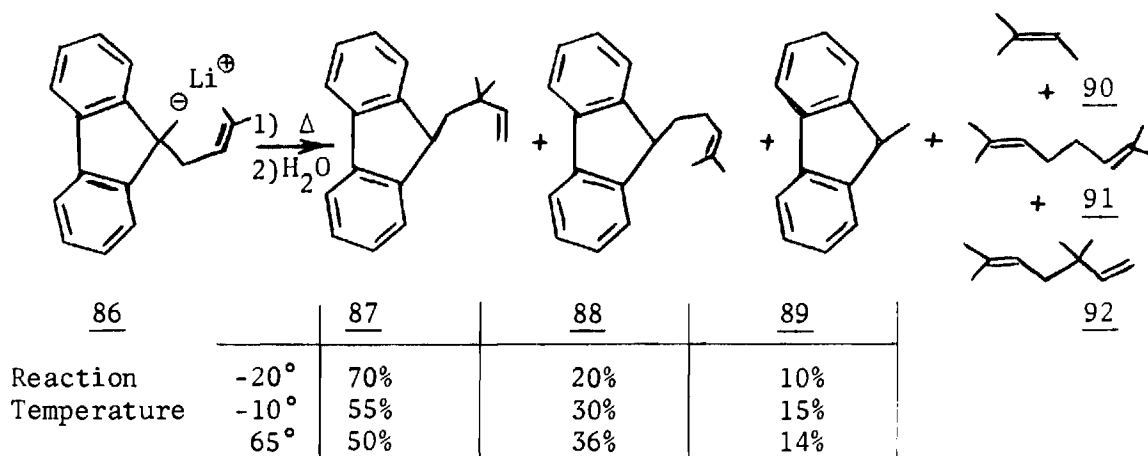
46. E. Grovenstein, Jr. and G. Wentworth, J. Amer. Chem. Soc., **85**, 3305 (1963).



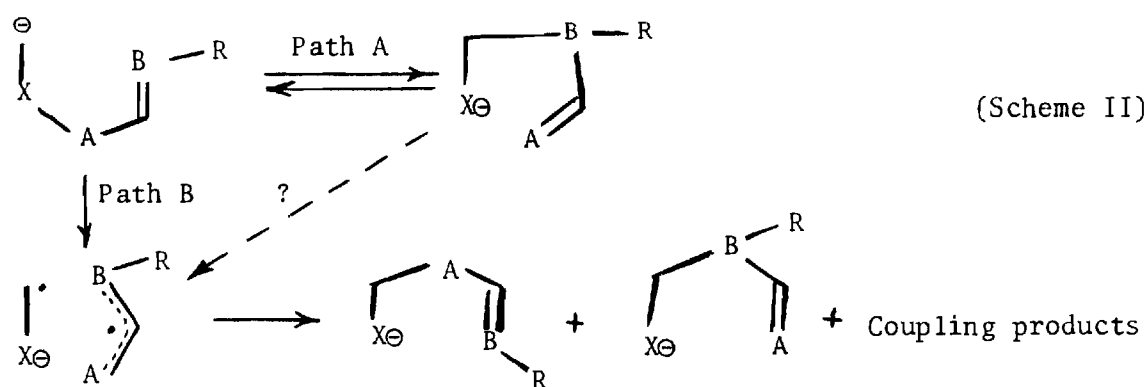
A similar system was reported by Baldwin⁴⁷ in which 9-(3-methylbut-2-enyl)-9-(lithiomethyl)-fluorene, 86, underwent allylic migration to 9-(2,2-dimethylbut-3-enyl)-9-lithiofluorene and other products shown. The ratio of rearrangement products was somewhat temperature dependent and a dual mechanism was invoked to explain the results: (1) a reversible [3,2]-sigmatropic rearrangement⁴⁸ and (2) an irreversible homolytic dissociation-recombination mechanism. A demonstration of the reversible nature of the sigmatropic mechanism was achieved when the rearrangement was allowed to go to completion at -20° to give primarily product 87; the reaction mixture was then allowed to stand at 25° for 36 hours and was quenched to give essentially the products (88-92) expected from a radical cleavage-recombination process.

47. J. E. Baldwin and F. J. Urban, Chem. Commun., 165 (1970).

48. Baldwin also suggests a duality of mechanism in certain [3,3]-sigmatropic rearrangements. J. E. Baldwin and J. A. Walker, J. Amer. Chem. Soc., 96, 596 (1974).



Based on this finding and consistent with his earlier work on diazene,⁴⁹ sulfonium,³³ and ether rearrangements³⁶ and the work of others concerning 1,2-migrations, Baldwin proposed a general ylid mechanism in which the products of simultaneous rearrangement resulting from sigmatropic and/or a radical-pair mechanism could be rationalized³³⁻³⁶ (Scheme II).



49. J. E. Baldwin and J. E. Brown, J. Amer. Chem. Soc., 93, 788 (1971).

Whether Baldwin's proposed mechanism or that of other investigators regarding carbanion/carbanionoid rearrangements is valid has yet to be determined. But with the increased use of allylic rearrangement in the synthesis of organic compounds ranging from the more classical functional synthesis⁵⁰ to that of natural products⁵¹ and antibiotics,⁵² it is deemed important that anionic allylic rearrangement in an all carbon-skeleton be explored further so that we can (1) add to our capability of stereo-predetermined synthesis and (2) better understand carbanionic systems.

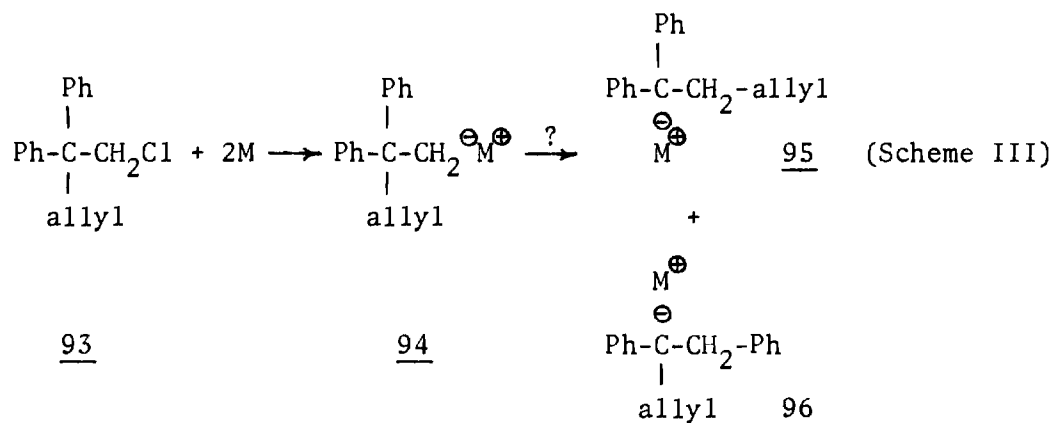
The study of the rearrangement of 2,2-diphenyl-4-pentenyl alkali metal compounds was undertaken as a thesis topic as an extension of the work begun by Grovenstein.⁴² The plan of study was to prepare the anion from the corresponding chloride by the action of alkali metal at low temperature (-75°) (Scheme III). If successful, the plan of study was to (1) determine the thermal stability of the carbanion, (2) determine the parameters necessary to effect rearrangement, (3) determine the products of rearrangement, i.e., did allyl or phenyl migrate, and

50. (a) H. Felkin and A. Tambute, Tetrahedron Lett., 821 (1969); (b) R. E. Ireland and R. H. Mueller, J. Amer. Chem. Soc., 94, 5897 (1972); (c) P. A. Grieco, J. Chem. Soc., Chem. Commun., 702 (1972); (d) R. E. Hackler and T. W. Balko, J. Org. Chem., 38, 2106 (1973); (e) J. N. Mander and J. V. Turner, J. Org. Chem., 38, 2915 (1973); (f) P. T. Lansbury and J. E. Rhodes, J. Chem. Soc., Chem. Commun., 21, (1974); (g) R. I. Trust and R. E. Ireland, Org. Syn., 53, 116 (1973).

51. (a) P. A. Grieco and R. S. Finkelhor, J. Org. Chem., 38, 2245 (1973); (b) D. Michelot, G. Linstrumelle, and S. Julia, J. Chem. Soc., Chem. Commun., 10 (1974).

52. G. V. Kaiser, C. W. Ashbrook, and J. E. Baldwin, J. Amer. Chem. Soc., 93, 2342 (1971).

(4) propose a feasible mechanism to explain the results.



With these basic goals in mind, the study evolved from a classical series of repetitive experiments with compounds containing a labeled allyl group to a system whereby the fundamental nature of the rearrangement of allyl (^{14}C -label) vs phenyl was investigated in tetrahydrofuran. The system was treated with potassium butoxide and crown ether, separately and in combination. The following is a description of the work, a discussion of the results, and suggestions for further work.

CHAPTER II

REAGENTS AND SOLVENTS*

Acetic Acid, Glacial

Baker analyzed reagent grade glacial acetic acid was used.

Acetone

Commercial grade acetone was distilled at 56° through a 120-cm Vigreux column.

Acetone-d₆

Diaprep, Inc. (99.5 percent minimum isotopic purity) was used without further purification.

Allyl Alcohol

Baker grade (bp 95°-98°) 3-propen-1-ol was distilled at 96°-97° through a 15-cm Vigreux column.

Allyl-1-¹⁴C Alcohol

Tracerlab (0.5 mC) and International Chemical & Nuclear (0.1 mC) were the suppliers of the 3-propen-1-ol-1-¹⁴C used in this study.

Allyl Chloride

Baker grade (bp 44°-45°) 3-chloropropene was distilled at 45° through a 15-cm Vigreux column and was stored over Drierite or

*Used as stated unless otherwise noted in the experimental text.

molecular sieve immediately prior to use.

Allyl Phenyl Ether

Aldrich reagent grade allyl phenyl ether was found to be 99 percent pure and was used without further purification.

Alumina

Merck alumina (70-300 mesh) was acid washed and used for chromatographic adsorption.

Ammonia

Matheson Co., Inc. anhydrous ammonia gas (99.9 percent minimum purity) was passed through a 60-cm U-tube containing granules of barium oxide and potassium hydroxide prior to condensation in the reaction vessel in which it was to be used.

Ammonium Chloride

Baker analyzed reagent and Fisher certified ACS grades of ammonium chloride were used without further purification.

Barium Oxide

Fisher grade of porous lumps of anhydrous barium oxide were used without further purification.

Benzene

Baker commercial grade, Baker analyzed reagent, and Fisher certified ACS (all thiophene free) benzene was distilled at 80° through a 30-cm Vigreux column and stored over sodium wire.

Benzoic-¹⁴C Acid

Chem Trac Corporation (0.2522 $\mu\text{C}/\text{mmole}$ -specific activity) supplied the crystals of benzoic-¹⁴C acid calibration standard and they were not purified further.

1,2-Bis(2-chloroethoxy)ethane

Eastman practical grade 1,2-bis(2-chloroethoxy)ethane was used without further purification.

tert-Butyl Alcohol

Baker reagent grade 2-methyl-2-propanol was distilled from sodium through a 100-cm Vigreux column.

n-Butyl Chloride

Columbia Organic Chemicals Co., Inc. reagent grade of 1-chlorobutane was distilled at 70° through a 30-cm Vigreux column.

n-Butyllithium

Foote Mineral Co. supplied the 2M solution of n-butyllithium in hexane.

Calcium Chloride

Fisher reagent grade anhydrous calcium chloride (4-20 mesh) was used without further purification.

Carbon Dioxide

Matheson Co., Inc. Bone Dry grade of gaseous carbon dioxide was used without further purification.

Carbon Disulfide

Baker analyzed reagent grade of carbon disulfide was used without further purification.

Carbon Tetrachloride

Baker analyzed reagent grade of carbon tetrachloride was used without further purification.

Cesium

MSA Research Corporation supplied cesium metal in sealed ampoules and it was used without further purification.

Charcoal, Activated

Atlas Chemical Industries, Inc. supplied the activated charcoal (DARCO) and no further purification was required.

Chloroform

Mallinckrodt Company U.S.P. grade chloroform was distilled at 61° through a 30-cm Vigreux column.

Chloroform-d

Merck, Sharp, & Dohme and Diaprep nmr grade chloroform-d was supplied in sealed ampoules and used without further purification.

Chlorotrimethylsilane

Eastman Organic Chemicals practical grade chlorotrimethylsilane was used without further purification.

Cyclohexane

Phillips Petroleum Company (99.5 weight percent minimum) cyclohexane was used without further purification.

Deuterium Oxide

A stock supply of deuterium oxide containing 99.8 atoms percent deuterium was used without further purification.

Diazomethane

Diazomethane was prepared according to the ethanolic/ether procedure from "DiazaId" which was obtained from Aldrich Chemical Company.

Di-n-butyl Ether

Eastman Organic Chemicals practical grade di-n-butyl ether was stored over sodium metal and then distilled at 140° through a 15-cm Vigreux column prior to use.

Diethyl Ether

Fisher anhydrous reagent and Baker anhydrous analyzed reagent grades of diethyl ether were stored over sodium wire and used without further purification.

Dimethyl Sulfoxide-d₆

Merck, Sharp, & Dohme grade dimethyl sulfoxide-d₆ (99.5 atom percent D) was supplied in sealed ampoules and used without further purification.

2,4-Dinitrophenylhydrazine

Eastman Organic Chemicals grade 2,4-dinitrophenylhydrazine was used without further purification.

Diphenylacetic Acid

Aldrich puriss grade diphenylacetic acid was used without further purification.

1,1-Diphenylethene

Aldrich technical grade (90 percent minimum) of 1,1-diphenylethene was used without further purification.

Diphenylmethane

Eastman Organic Chemicals practical grade (> 99 percent pure by vpc) diphenylmethane was used without further purification.

3,3-Diphenylpropanoic Acid

Aldrich grade 3,3-diphenylpropanoic acid was used without further purification.

Calcium Sulfate, Anhydrous

W. A. Hammond Drierite Company supplied the "Drierite" and it was not reclaimed for re-use.

Dry Ice

Airco supplied blocks of "dry ice" which were broken up and pulverized for further use.

Ethanol, Absolute

Commercial absolute ethanol was used without further purification.

Ethanol, 95 Percent

Commercial 95 percent ethanol was used without further purification.

Ferric Nitrate

Baker analyzed reagent grade of ferric nitrate (nine hydrate) crystals were used without further purification.

Hexamethylphosphoramide

Aldrich grade hexamethylphosphoramide was used without further purification.

n-Hexane

Phillips Petroleum Company pure grade (99 mol percent minimum purity) n-hexane was used without further purification.

Insta-Gel

Packard Instrument Company supplied the "Insta-Gel" which was used without further purification.

Hydrochloric Acid

Fisher reagent ACS grade concentrated hydrochloric acid was used without further purification.

Hydrogen

Commercial grade hydrogen gas was used without further purification.

Lead Dioxide

Baker analyzed reagent lead dioxide dust was used without further purification.

Lithium

Lithium Corporation of America supplied the 1/8" diameter lithium wire (containing less than 0.05 percent sodium). The wire was cut into small 1/8" lengths, washed twice with diethyl ether, and then dried in a nitrogen stream and then was immediately introduced into the reaction flask.

Lithium Aluminum Hydride

Ventron Corporation supplied the lithium aluminum hydride powder which was used without further purification.

Magnesium

Fisher (turnings for Grignard reactions) grade of magnesium was used without further purification.

Magnesium Sulfate, Anhydrous

Fisher certified grade of anhydrous magnesium sulfate was used without further purification.

Methanol

Commercial grade of methanol was distilled at 65° through a 30-cm Vigreux column.

Methone

Eastman Organic Chemicals white label grade of methone was used without further purification.

Methylene Chloride

Baker reagent grade methylene chloride was distilled at 41° through a 30-cm Vigreux column.

Methyl Iodide

Eastman Organic Chemicals white label grade of methyl iodide was used without further purification.

Methyl Phenylacetate

Aldrich reagent grade of methyl phenylacetate (99.0 plus percent) was used without further purification.

Molecular Sieve

Linde grade of molecular sieve (4A) was used without further purification.

Nitric Acid

Fisher reagent ACS grade of concentrated nitric acid was used without further purification.

Osmium Tetraoxide

Baker and Adamson reagent grade of osmium tetraoxide was supplied in a sealed ampoule and was used without further purification.

n-Pentane

Eastman Organic Chemicals practical grade of n-pentane was used without further purification.

Phenyllithium

Ventron Corporation supplied the phenyllithium solution (2 M in 70:30 benzene:ether) and was used without further purification.

p-Phenylphenacyl Bromide

Eastman Organic Chemicals reagent grade of p-phenylphenacyl bromide was used without further purification.

Phenol

Mallinckrodt ACS reagent grade of phenol was used without further purification.

Phosphoric Acid

Baker analyzed reagent grade of concentrated phosphoric acid was used without further purification.

5 Percent Platinum on Charcoal

Engelhard Industries, Inc. supplied the 5 percent platinum on charcoal which was used without further purification.

Potassium

Baker analyzed reagent and Fisher grade sticks of potassium metal were cut, washed twice with diethyl ether, dried in a stream of nitrogen and introduced into the reaction flask.

Potassium Bromide

Baker analyzed reagent grade of potassium bromide was dried at 120° for 6 hours and cooled.

Potassium Chloride

Fisher certified ACS grade of potassium chloride was used without further purification.

Potassium Dichromate

Baker analyzed reagent grade of potassium dichromate was used without further purification.

Potassium Hydroxide

Baker analyzed reagent grade of anhydrous potassium hydroxide pellets were used without further purification.

Potassium Iodate

Baker analyzed reagent grade of potassium iodate was used without further purification.

Potassium Iodide

Fisher certified ACS grade of potassium iodide was used without further purification.

Silica Gel

E. Merck A.-G. Darmstadt supplied the silica gel (70-325 mesh) which was used without further purification for adsorptive chromatography.

Sodium

Baker purified lump grade of sodium metal was cut, washed twice with diethyl ether, and air dried prior to being pressed into wire.

Sodium Aluminum Hydride

Ventron Corporation supplied the sodium aluminum hydride powder which was used without further purification.

Sodium Carbonate

Fisher reagent ACS grade of sodium carbonate was used without further purification.

Sodium Dihydrogen Phosphate

Baker analyzed reagent grade of sodium dihydrogen phosphate was used without further purification.

Sodium Hydroxide

Fisher U.S.P. grade of sodium hydroxide pellets was used without further purification.

Sodium Iodide

Fisher certified grade of sodium iodide was used without further purification.

Sodium meta-Periodate

Fisher ACS certified reagent grade of sodium meta-periodate was used without further purification.

Sodium Tetraphenylborate

Fisher certified ACS grade of sodium tetraphenylborate was used without further purification.

Stannous Chloride

Baker technical grade of stannous chloride (dihydrate crystals) was used without further purification.

Sulfuric Acid

Fisher reagent ACS grade of concentrated sulfuric acid was used without further purification.

Sulfuric Acid, Fuming

Baker grade fuming sulfuric acid was used without further purification.

Tetrahydrofuran

Baker analyzed reagent grade of tetrahydrofuran was stored over sodium wire and distilled from sodium lithium aluminum hydride directly into the reaction flask to be used.

Tetrahydrofuran-d₈

Norell Chemical Company, Inc. supplied tetrahydrofuran-d₈ (99 atom percent D) in sealed ampoules and it was used without further purification.

Tetramethylsilane

Aldrich nmr grade (99.9 percent purity) of tetramethylsilane was used without further purification.

Thionyl Chloride

Fisher reagent grade of thionyl chloride was used without further purification.

Toluene

Baker analyzed reagent grade toluene was used without further purification.

Tri-n-butylamine

Baker grade of tri-n-butylamine (91°-93°/10mm) was stored over anhydrous potassium hydroxide pellets and was used without further purification.

Triethylene Glycol

Fisher purified grade of triethylene glycol was used without further purification.

Triphenylboron

Ventron Corporation grade of triphenylboron (mp 144°-149°) was supplied in a sealed ampoule and was used without further purification.

Zinc

Fisher certified reagent grade zinc dust was used without further purification.

CHAPTER III

INSTRUMENTATION AND GENERAL PROCEDURES

Proton magnetic resonance spectra (nmr) were run on a 60 MHz Varian, A-60D; 60 MHz Varian, T-60; and/or a 100 MHz JNM-JEOL, 4H-100, relative to internal tetramethylsilane (TMS). Melting point determinations were made with use of a Mel-Temp apparatus; only uncorrected values are reported in this thesis but corrections may be made according to Figure 1.* Infrared spectra were run on a Perkin-Elmer, model 237B, grating spectrophotometer and calibrated with the 1101.4 cm^{-1} band of polystyrene. Ultraviolet-visible spectra were obtained upon a Cary-14 spectrophotometer.

Mass spectra were run on a Varian model A-66 (equipped with Varian Aerograph Series 200 gas chromatograph with Varian V-5500 MS/GC Interface) and a Hitachi-Perkin-Elmer, model RMU-7L. Peak heights were determined relative to the most intense ion (100%) by use of a Gerber variable scale, model TP007100B or ratio measurement by rule.

Gas chromatography (vpc) was accomplished on a Perkin-Elmer Chromatograph (PE), model 881, and F & M Research Chromatograph (F & M), model 810. Stainless steel injector blocks and columns were used with nitrogen as the carrier gas. Both instruments were equipped with hydrogen-flame ionization detectors. The columns used and typical operating conditions are given in Table 2. Gas chromatograms were

*See Table 1 for reported vs observed compound mp correlation.

Table 1. Reported vs Observed Melting Point Correlation

Compound	Reported	Observed
Benzophenone	48.0°	47.0°- 48.0°
Fluorene	116.0°	113.0°-114.0°
Benzoic Acid	122.0°	121.0°-122.0°
Malonic Acid	135.0°	132.0°-133.0°
Salicyclic Acid	157.0°	156.5°-157.5°
Triphenylmethanol	163.0°	161.0°-162.0°
Anthracene	216.5°	212.0°-213.0°
Tetraphenylmethane	282.0°	277.0°-277.5°

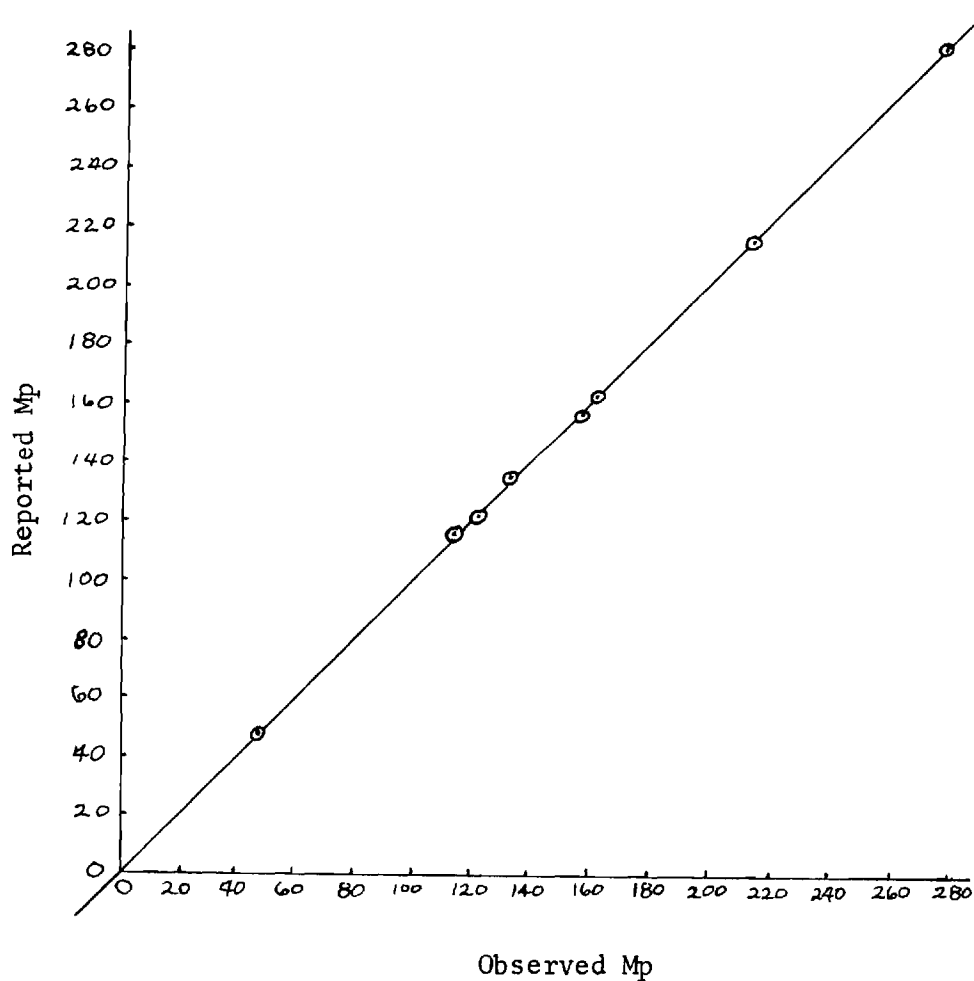


Figure 1. Thermometer Calibration for Mel-Temp Apparatus

Table 2. Columns Used in Gas Chromatographic Analysis

Column A:	6'--1/8"--5% Apiezon L on 80/100 Variport (200°, 175°, 190°, 3.0)*
Column B:	12'--1/8"--5% SE-30 on 80/100 Chromosorb W (225°, 200°, 215°, 3.0)
Column C:	6'--1/8"--5% SE-30 on 80/100 Chromosorb W (250°, 160°, 185°, 2.0)
Column D:	6'--1/8"--10% Apiezon L on 60/80 Chromosorb W (250°, 180°, 205°, 1.5)
Column E:	10'--1/8"--15% Carbowax 20M on 60/80 Chromosorb W (270°, 167°, 235°, 4.0)
Column F:	20'--1/8"--15% Apiezon H on 60/80 Chromosorb W (285°, 200°, 280°, 1.5)
Column G:	12'--1/8"--15% Apiezon H on 60/80 Chromosorb W (270°, 200°, 230°, 3.0)
Column H:	6'--1/8"--5% Apiezon L on Diatoport S (245°, 150°-208°, 240°, 2.0)
Column I:	12'--1/4"--10% Apiezon L on 80/100 Chromosorb W (300°, 220°, 270°, 2.5)

*The sequence of numbers given for each column is as follows:
injector temperature, oven temperature, detector temperature, and the
flow rate.

analyzed by determining the area of the (triangular) peaks (height x width at one-half the height). Qualitative vpc yields are given in relative peak areas whereas absolute quantitative vpc yields are based on an internal standard and known samples.

A standard Morton apparatus is a three-necked, indented Morton flask under nitrogen (Hg-bubbler) which was equipped with a Dry Ice-acetone condenser (using liquid ammonia as solvent) or Friedrich condenser (using solvents such as THF), high-speed stainless steel (ss) stirrer assembly, and pressure equalizing dropping funnel. The flask was dried under nitrogen by heating with a 1000-watt air-blower gun and cooling to room temperature under nitrogen and THF was distilled from NaAlH_4 .

A modified Morton apparatus (Figure 2) was the same as the "standard Morton apparatus" except for the fact there were six necks. The three additional necks accommodated a thermometer well, a 4-mm bore Teflon stopcock for sampling, and an internal siphon tube with vacuum stopcock.

Preparation of Potassium Amide

In a standard Morton apparatus was condensed ca. one-half volume liquid ammonia. Potassium metal was added with the ammonia at ca. -50° under an atmosphere of nitrogen. The immediate formation of a dark blue-black solution indicated formation of solvated electrons.⁵³ After

53. (a) J. Jortner and N. R. Kestner, Ed., Electrons in Fluids; The Nature of Metal-Ammonia Solutions, Springer-Verlag New York, Inc., New York, NY, 1973; (b) R. F. Gould, Ed., Solvated Electrons, Advances in Chemistry Series 50, Amer. Chem. Soc., Washington, D.C., 1965.

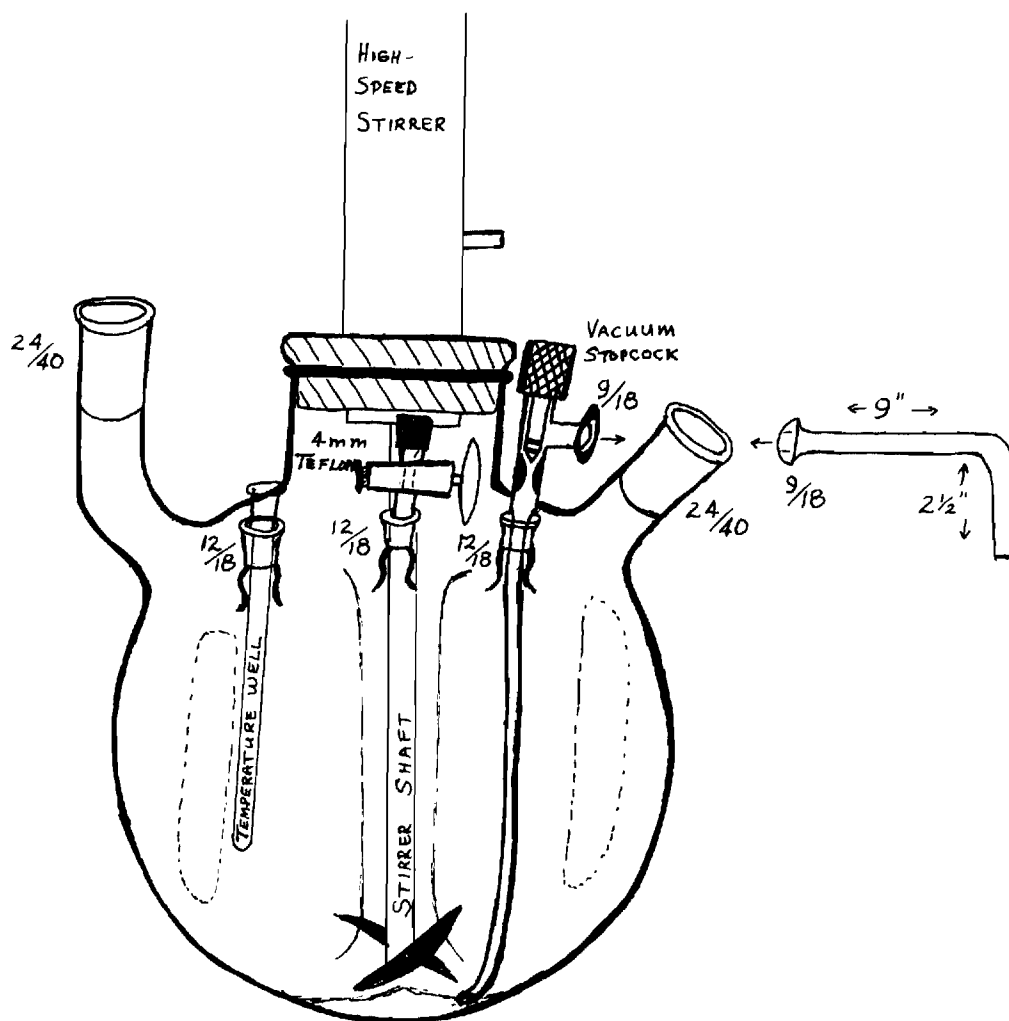


Figure 2. Modified Morton Apparatus Designed for the Preparation, Reaction, and Transfer of Organoalkali Solutions

the potassium dissolved, a few (ca. 2) crystals of $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ was added and stirring begun to effect formation of KNH_2 . One hour of stirring at reflux (-33°) was generally sufficient for complete formation of KNH_2 as was indicated by formation of a clear brownish-gray solution (unreacted potassium in the neck of the flask was washed down by rapid stirring and allowed to react also). This reagent solution was then used subsequently.

Oxidation of Olefins by Ozonization⁵⁴ and
Preparation of Methone Derivatives

The compound to be oxidized was dissolved (ca. 0.1 g) in 50 ml of chloroform in a 10-inch T 45/50 gas-drying apparatus with glass frit and cooled to $-50^\circ \pm 5^\circ$. A stream of ozone-oxygen (generated by a Welsbach, model T-23, ozonizer; oxygen tank 25 psi, generator regulator 3 psi, flowmeter 0.0015-0.500, 90v) was bubbled through the primary reaction solution and secondary chloroform trap for ca. 7.5 min until the indicating soln (2% $\text{KI-NaH}_2\text{PO}_4$, 1 mole/1 mole) was a definite dark amber-brown. The ozone flow was discontinued and the clear bright blue ozonide-chloroform solution was combined with the contents of the secondary trap containing 20-25 ml of chloroform and was added to a 300-ml Erlenmeyer flask containing 25 ml water, 25 ml acetone, 2 ml glacial acetic acid, 1.0 g zinc dust, and a magnetic stirring bar. The combined reduction mixture was stirred 30-40 min at room temperature

54. (a) Suresh Chandra, Ph.D. Thesis, Georgia Institute of Technology, Atlanta, GA, 1961, p. 83; (b) P. S. Bailey, Chem. Reviews, 58, 925 (1958); (c) F. Dobinson and P. S. Bailey, Tetrahedron Lett., 13, 14 (1960).

and filtered to remove the zinc. The filtrate was added to a 250-ml Erlenmeyer flask containing an appropriate amount of "methone" in 25 ml of 95% ethanol. This solution was allowed to stir or stand overnight, and after addition of 50 ml H_2O , the chloroform-acetone was removed on a steam bath. The flask was cooled in the refrigerator to effect crystal formation. The crystals were separated by filtration and recrystallized from 95% ethanol to yield fragile white needles of the methone derivative of formaldehyde, mp 190.0° - 191.0° .⁵⁵

Oxidation of Olefins by OsO_4 ⁵⁶ and
Preparation of Derivatives

The compound (ca. 0.1 g) to be oxidized was placed in a 50-ml flask and dissolved in 10 ml of ether. To this solution was added 5 ml of an ethereal solution containing 0.0366 g (0.000144 g-formula wt) of OsO_4 . The reaction solution turned amber-black in ca. 5 min and 15 ml of water was added. The heterogeneous solution was stirred by a magnetic stirring bar for ca. 15 min (solution was darker--almost black) and two moles of $NaIO_4$ (per mole olefin) was added with continued stirring overnight at room temperature. After 12 hours reaction time, the ether layer (clear amber tint) was separated from the aqueous layer (clear and colorless). The ether layer was washed with 5 ml of

55. Mp reported to be 191.0° - 191.5° . E. C. Horning and M. G. Horning, J. Org. Chem., 11, 95 (1946).

56. (a) L. F. Fieser and M. Fieser, Reagents for Organic Synthesis, John Wiley & Sons, Inc., New York, NY, 1967, p. 759; (b) P. N. Rylander, Technical Bulletin, 9, (3), 90 (1968), Englehard Industries, Inc.; (c) R. Pappo, D. S. Allen, Jr., R. U. Lemieux, and W. S. Johnson, J. Org. Chem., 21, 478 (1956).

water and the combined aqueous phase was added to an appropriate quantity of "methone" in 25 ml 95% ethanol. After one hour fine needles began forming. The reaction flask was allowed to stand at room temperature overnight and then cooled in the refrigerator. The crystals were separated by filtration, washed with water, and recrystallized if necessary to yield white needles of reported mp for the formaldehyde methone derivative.

The ether phase from the OsO_4 oxidation was filtered through anhyd MgSO_4 and concentrated to dryness. The residue was dissolved in 5 ml 95% ethanol and added to a freshly prepared 2,4-dinitrophenylhydrazine (2,4-DNP) reagent according to the procedure of Shriner, Fuson, and Curtin.⁵⁷

Radioactive Assay

Radioactive assay was accomplished by two independent methods: (1) combustion of the compound and counting the radioactivity of the collected carbon dioxide by the steady-deflection method using an Applied Physics Corporation, model 31, vibrating reed electrometer (VRE) and (2) by dissolving the compound to be assayed in a phosphor solvent and counting the radioactivity by liquid scintillation on a Nuclear-Chicago, model Mark I, liquid scintillator (LS).

Assay by combustion was carried out by the procedure of Chandra⁵⁸ except for the fact that the PbO_2 tube was not in the

57. R. L. Shriner, R. C. Fuson, and D. Y. Curtin, The Systematic Identification of Organic Compounds, 5th ed., John Wiley & Sons, Inc., New York, NY, 1964, p. 253.

58. Reference 54a, p. 87.

combustion line unless the compound to be assayed contained nitrogen. All weighings were in a platinum boat (solids) or a glass boat (liquids) and were determined on a microbalance.

Assay by liquid scintillation⁵⁹ was carried out by weighing the compound directly into plastic scintillation vials on a microbalance and dissolving the compound in 10.0 ml of the phosphor solvent, Insta-Gel.⁶⁰ The vials were then placed in a liquid scintillator at $9^{\circ} \pm 1^{\circ}$ and counted.

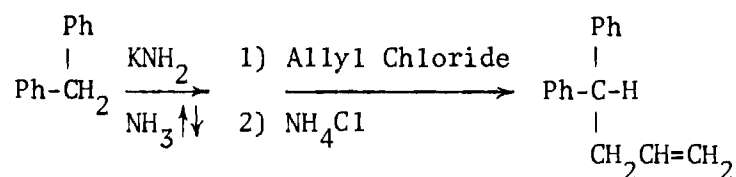
Specific activities of all compounds assayed were determined in microcuries per millimole relative to a benzoic acid standard of known specific activity.

59. J. H. Parmentier and F. E. L. Ten Haaf, Int. J. Appl. Radiat. Isotopes, 20, 305 (1969).

60. Insta-Gel is a gel-phosphor useful for either aqueous or non-aqueous samples which is available from Packard Instrument Co. Further details are available from Packard, Bulletin 405 E; however, the composition of the Insta-Gel is unknown since such information is not released by the manufacturer.

CHAPTER IV

EXPERIMENTAL DETAILS

Syntheses and PreparationsSynthesis of 4,4-Diphenyl-1-butene⁶¹ (54-I) *

In a standard 2000-ml Morton apparatus was condensed 800 ml of ammonia. Potassium amide was made from 28.64 g (0.734 g-atom) potassium metal and then 105.4 g (0.627 mole) of diphenylmethane in 150 ml anhyd ether was added dropwise over a 15 min period to the solution at -33° . The solution turned yellowish-red upon addition of the first drop of hydrocarbon and continued to develop a deeper red color until completion of the addition. After the red solution had been stirred for 30 min at reflux, 50 g (0.655 mole) of allyl chloride was added dropwise in 25 ml anhyd ether. Addition of the chloride was at a rate such that the solution did not react too violently since rapid reaction (exothermic) was observed on contact. The reaction solution went from a reddish-black

61. S. G. Kuznetsov and N. M. Libman, Zh. Org. Khim., 1, 1399 (1965) synthesized 4,4-diphenyl-1-butene according to the procedure given in the text.

*The Arabic numeral refers to the page number and the Roman numeral to the laboratory notebook number.

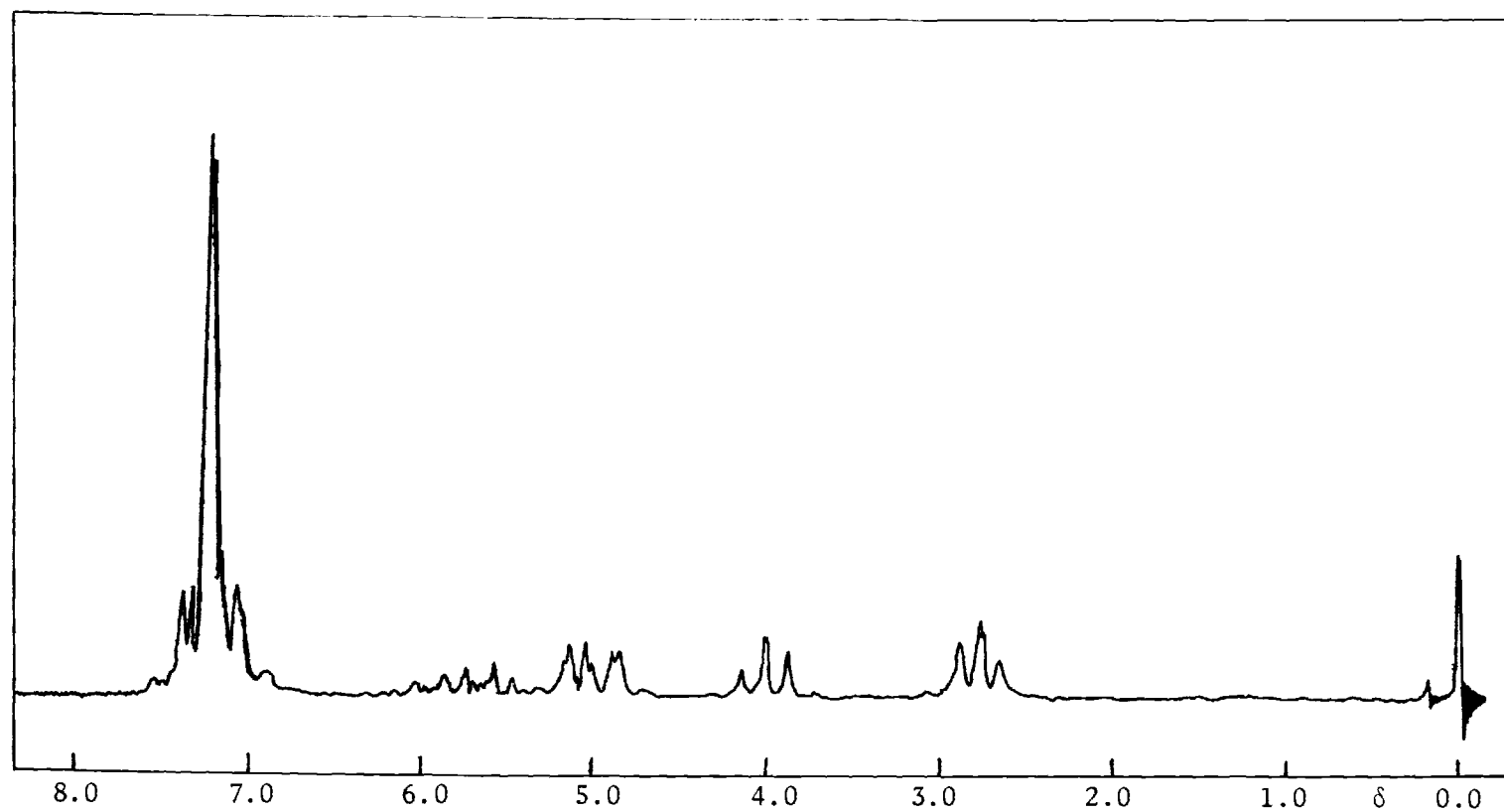
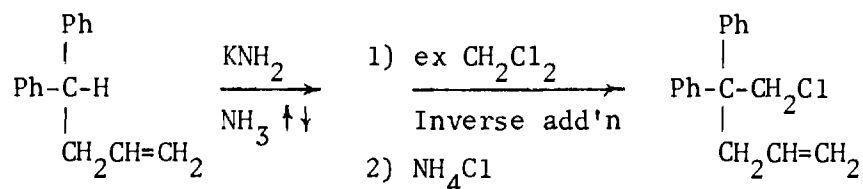


Figure 3. Nmr Spectrum (neat) of 4,4-Diphenyl-1-butene (54-I)

to brownish-orange to a slightly greenish color on addition of the chloride. After 5 min more of stirring, the unreacted KNH_2 was quenched with 16.30 g (0.305 mole) of NH_4Cl to give a cream-colored solution. The ammonia was allowed to evaporate overnight in the hood and the workup initiated by addition of water and ether. The ether extract was reduced in volume and the crude reaction product (vpc relative ratio--2.8% diphenylmethane; 97.2%, 4,4-diphenyl-1-butene) was vacuum distilled at bp $100^\circ/60\mu$. The absolute yield after distillation was 114.0 g (87.4% based on diphenylmethane) of 99.2% purity. Seven other preparations gave an average yield of 82%. The nmr spectrum (neat) had absorption at δ 2.75 (2.0 H, t, $J = 7.5$ Hz, $-\text{CH}_2-\text{CH}=\text{CH}_2$), 4.00 (1.0 H, t, $J = 8.0$ Hz, $\text{Ph}_2-\text{CH}-$), 5.00 (1.94 H, complex m, $J = 10.0$ Hz, $-\text{CH}=\text{CH}_2$), 5.65 (1.1 H, broad m, $-\text{CH}=\text{CH}_2$), and 7.20 (10.0 H, complex s, Ph_2-), which was consistent with that expected for 4,4-diphenyl-1-butene. The refractive index was found to be n_D^{20} 1.5704 (reported value⁶¹ n_D^{20} 1.5715), bp $115^\circ/2$ mm, and the density was 0.978 g/ml at room temperature.

Synthesis of 5-Chloro-4,4-diphenyl-1-pentene (59-I)



In a modified 2000-ml Morton apparatus was condensed 1000 ml of ammonia. Potassium amide was made from 39.36 g (1.007 g-atom) potassium metal and then 103.3 g (0.497 mole) 4,4-diphenyl-1-butene in 100 ml anhyd ether was added dropwise over a 20 min period to the solution at

-33°. The immediate formation of a red solution indicated carbanion formation. After 1.5 hr total reaction time at reflux the red-black solution was forced at -33° under nitrogen through an all glass siphon tube (over a 15 min period) into a 3000-ml round-bottom flask containing 400 ml, 530.6 g (6.25 mole) methylene chloride (freshly distilled, then treated with anhyd MgSO_4) at -75°. The reaction flask was stirred with a 4" Teflon mechanical blade stirrer until the red color of the solution disappeared completely (ca. 3-5 min reaction time) after which 30 g (0.56 mole) of NH_4Cl was added to quench the excess KNH_2 . The reaction mixture was exposed to the air and the ammonia allowed to evaporate in the hood overnight.

Workup was accomplished by removing all volatile liquids from the reaction mixture by use of a rotary evaporator at reduced pressure, addition of water, and extraction with ether. The ether extract which was filtered and dried over anhyd MgSO_4 contained 1.7% of an unknown compound, 4.7% starting hydrocarbon, and 93.6% desired product (the viscous clear liquid had a density of ca. 1.2 g/ml at 23.0°) according to a qualitative vpc analysis. The absolute yield after vacuum distillation at 127°/50 μ was 105.2 g (83.1% based on starting hydrocarbon) of 99.0% purity. Five other preparations had average yields of 79.5%. The nmr spectrum (CCl_4) had absorption at δ 1.05 (0.2 H, m, aliphatic impurity perhaps due to double bond shift to give a terminal methyl group), 1.69 (0.2 H, m, aliphatic impurity), 3.00 (1.8 H, d, $J = 5.5$ Hz, $-\text{CH}_2-\text{CH}=\text{CH}_2$), 4.09 (2.1 H, s, $-\text{CH}_2\text{Cl}$), 4.83-5.37 (2.9 H, complex m, $-\text{CH}_2-\text{CH}=\text{CH}_2$), 7.1 (10.0 H, s, Ph_2-), and was consistent with that

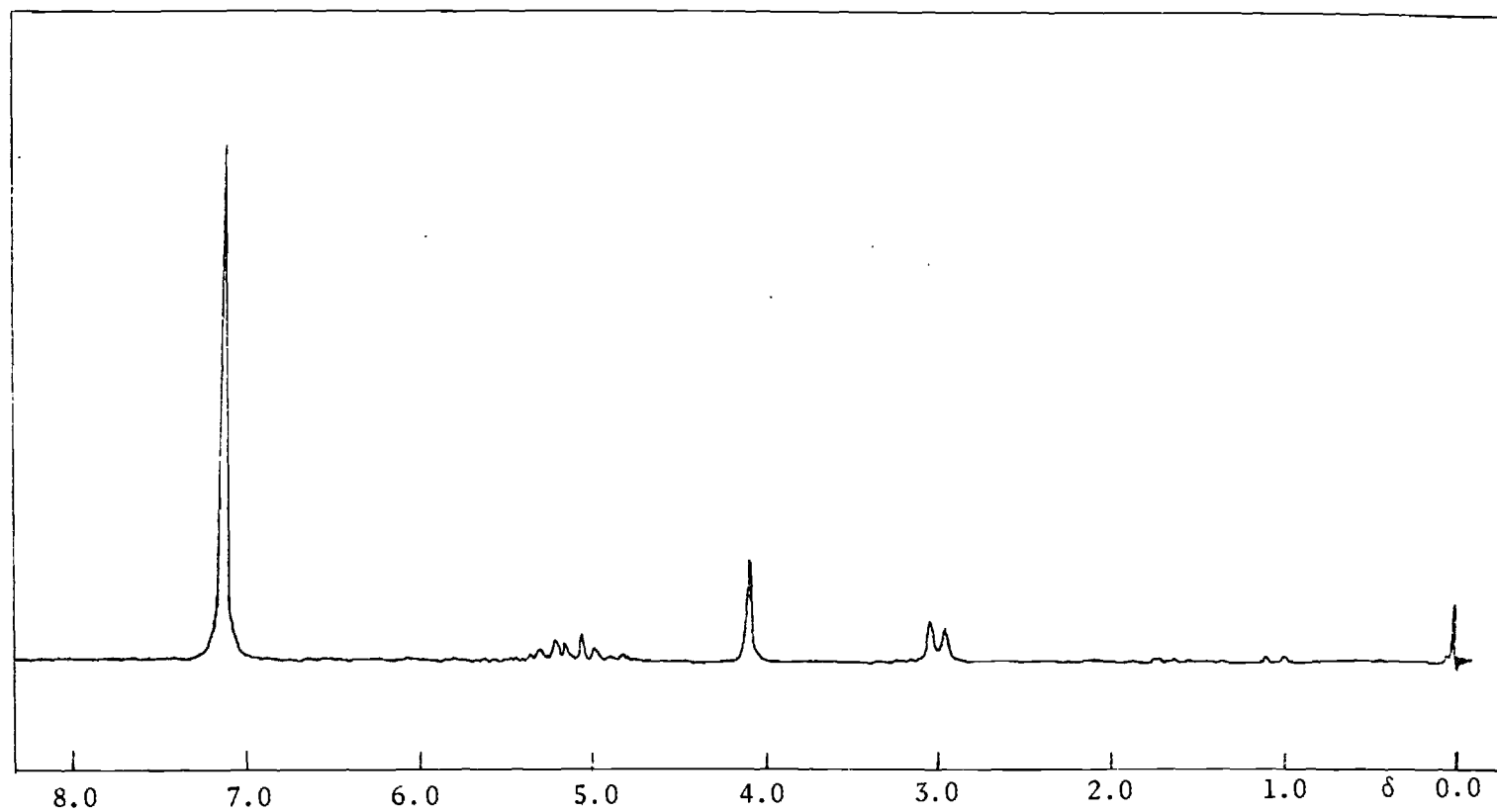
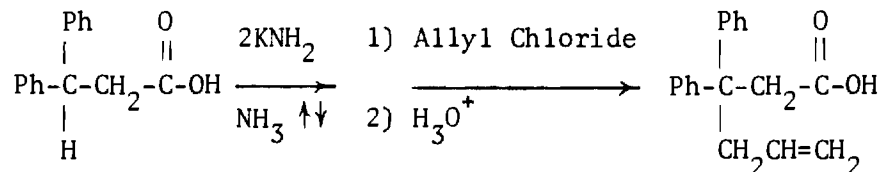


Figure 4. Nmr Spectrum (CCl_4) of 5-Chloro-4,4-diphenyl-1-pentene (59-I). (Figure 18 is a more resolved spectrum.)

expected for 5-chloro-4,4-diphenyl-1-pentene.*

Anal. (Galbraith)** Calcd for $C_{17}H_{17}Cl$: C, 79.52; H, 6.67; Cl, 13.81. Found: C, 79.52, 79.68; H, 6.87, 6.80; Cl, 13.66, 13.59.

Synthesis of 3,3-Diphenyl-5-hexenoic Acid (82-I)



In a standard 2000-ml Morton apparatus was condensed 1200 ml of ammonia. Potassium amide was made from 10.25 g (0.262 g-atom) of potassium metal after which 13.89 g (0.061 mole) of solid 3,3-diphenylpropanoic acid was added at reflux over a 7 min period to give a bright orange-red heterogeneous (suspended solid) soln. After 20 min of rapid stirring at reflux the soln became homogeneous and was a deep blood-red after 1 hr total elapsed time. Addition of 14.53 g (0.190 mole) of allyl chloride in 25 ml anhyd ether was completed over a 7 min period. The blood-red color disappeared after 12 min reaction time and continued stirring for an additional 30 min resulted in a brown-olive reaction mixture. After addition of excess NH_4Cl , evaporation of the ammonia in the hood, and addition of water, the reaction mixture was allowed to stand overnight. Workup was accomplished by extracting

*The estimated hydrocarbon impurity is estimated as $\leq 5\%$ according to vpc analysis. The identity of the chloride precursors (lower MW) are the only confirmed impurities.

**Elementary analyses were performed by Galbraith Laboratories, Inc., of Knoxville, TN and Atlantic Microlab, Inc., of Atlanta, GA as noted.

the neutral material with methylene chloride and acidifying the aqueous fraction with HCl followed by subsequent extraction of the free acid with methylene chloride, then ether. The combined methylene chloride with ether extract was dried over anhyd MgSO_4 and concentrated to give ca. 10.0 g of a viscous liquid (qualitative vpc of the crude methyl esters indicated the acid contained 25% starting acid and 75% of a new acid) for a crude acid yield of about 46%. Crystallization from pentane gave 3.40 g of impure acid. Recrystallization gave the acid in 95% purity (mp 98.0° - 104.0°). A better purification was obtained by chromatography of 0.41 g of a 90% pure sample on a 1.0" x 11-1/2" silica gel column with 2000 ml of chloroform as the eluant. The eluted soln (first fraction) was concentrated and the free acid was crystallized from pentane to yield 0.23 g acid crystals (mp 106.0° - 106.5°) of greater than 99% purity. The nmr spectrum (CCl_4) had absorption at δ 3.11 (3.9 H, unsymmetric d, $J = 4.0$ Hz, $-\text{CH}_2-\text{CH}=\text{CH}_2$ and $-\text{CH}_2-\text{CO}_2\text{H}$), 4.79-5.28 (2.8 H, m, $-\text{CH}_2-\text{CH}=\text{CH}_2$), 7.12 (10.2 H, s, Ph_2-), which was consistent with that expected for 3,3-diphenyl-5-hexenoic acid. The mass spectrum (Varian) of the free acid gave ions at 266 ($\ll 1$; M^+), 226 (18), 225 (100), 183 (68), 179 (13), 178 (21), 165 (29), 105 (24), 103 (50), 91 (12), 77 (21).

Anal. (Galbraith) Calcd for $\text{C}_{18}\text{H}_{18}\text{O}_2$: C, 81.15; H, 6.83.

Found: C, 81.36, 81.17; H, 6.89, 6.78.

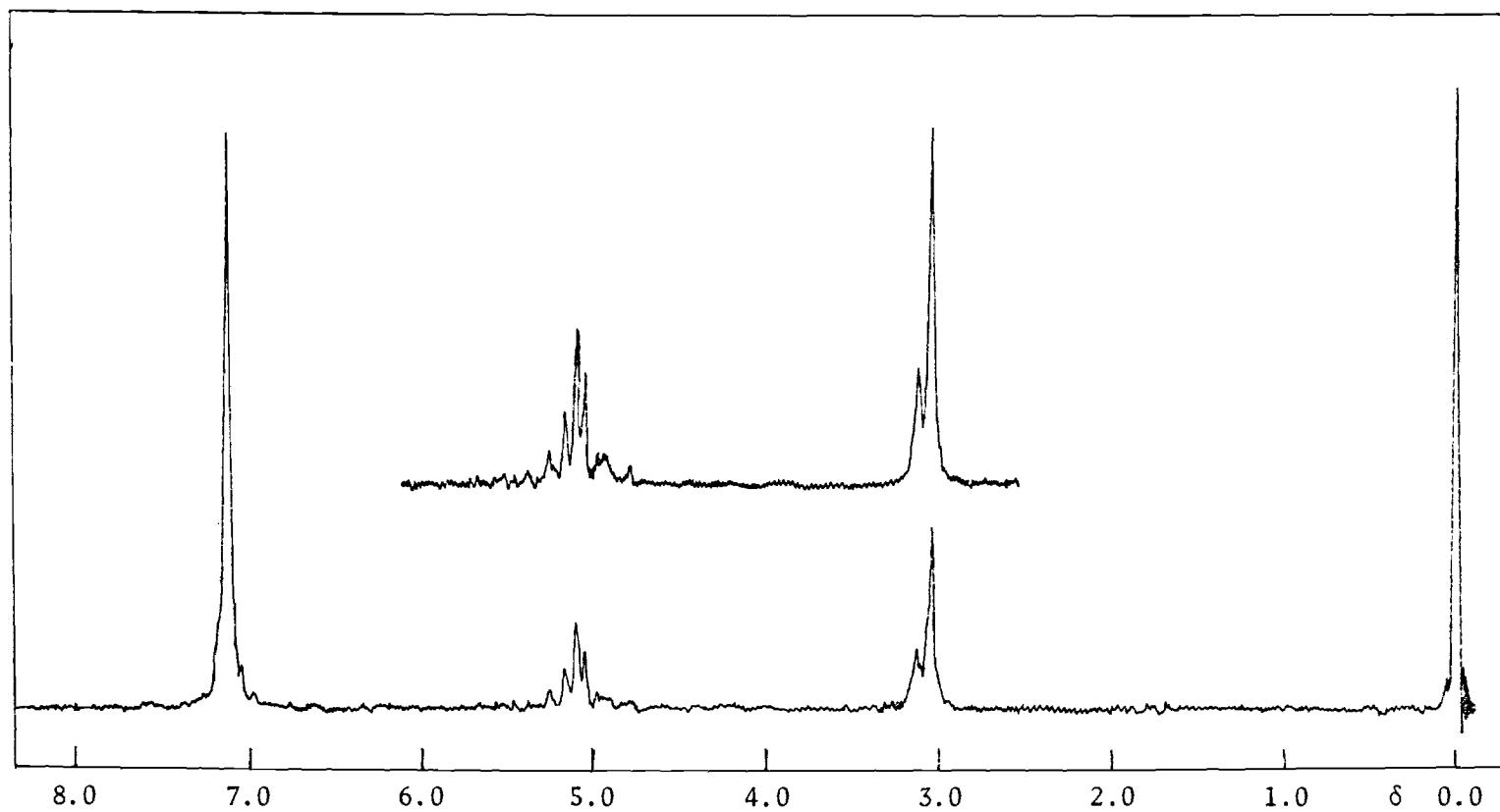


Figure 5. Nmr Spectrum (CCl_4) of 3,3-Diphenyl-5-hexenoic Acid (82-I)

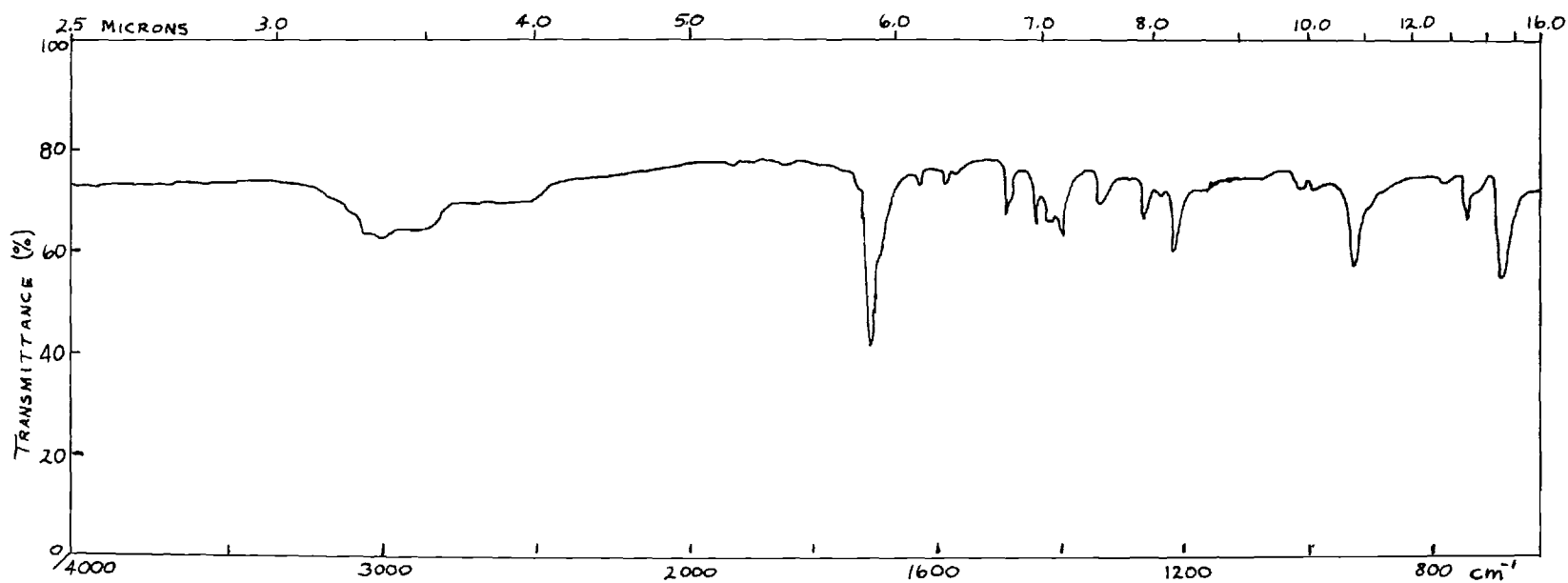
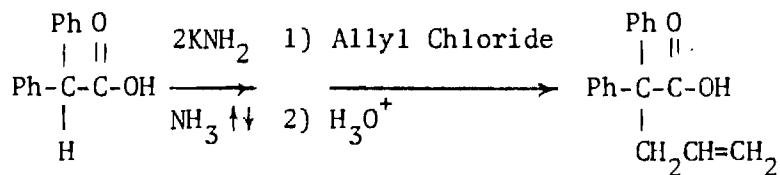


Figure 6. Infra-red Spectrum (KBr pellet) of 3,3-Diphenyl-5-hexenoic Acid (82-I)

Synthesis of 2,2-Diphenyl-4-pentenoic Acid⁶² (73-I)



In a standard 1000-ml Morton apparatus was condensed 400 ml of ammonia. Potassium amide was made from 21.76 g (0.556 g-atom) of potassium metal after which 53.06 g (0.250 mole) of solid diphenylacetic acid was added over a 15 min period. A yellow suspension formed immediately and was stirred for 30 min at reflux after which time 20.0 g (0.263 mole) of allyl chloride in 40 ml of anhyd ether was added over a 15 min period. No obvious reaction was observed and after 4.5 hr reaction time the ammonia was evaporated and 300 ml anhyd ether was added. Within 5 min the bright yellow reaction mixture went to pale yellow with formation of a heavy solid suspension.⁶³ The Dry Ice-acetone condenser was replaced by a Friedrich condenser and the mixture was heated on a steam bath. After 45 min at reflux, 300 ml of water was added, the mixture was stirred and allowed to stand at room temperature overnight. The ether and aqueous layers were separated. The ether layer was washed twice with 5% NaOH and the alkaline extract was

62. The reaction follows the general procedure of C. R. Hauser and W. J. Chambers, J. Amer. Chem. Soc., **78**, 4942 (1956).

63. Greater solubilization of the dianion and increased rate of alkylation is reported for the α -lithiation of carboxylic acids in THF by the addition of HMPA. P. E. Pfeffer, L. S. Silbert, and J. M. Chirinko, Jr., J. Org. Chem., **37**, 451 (1972).

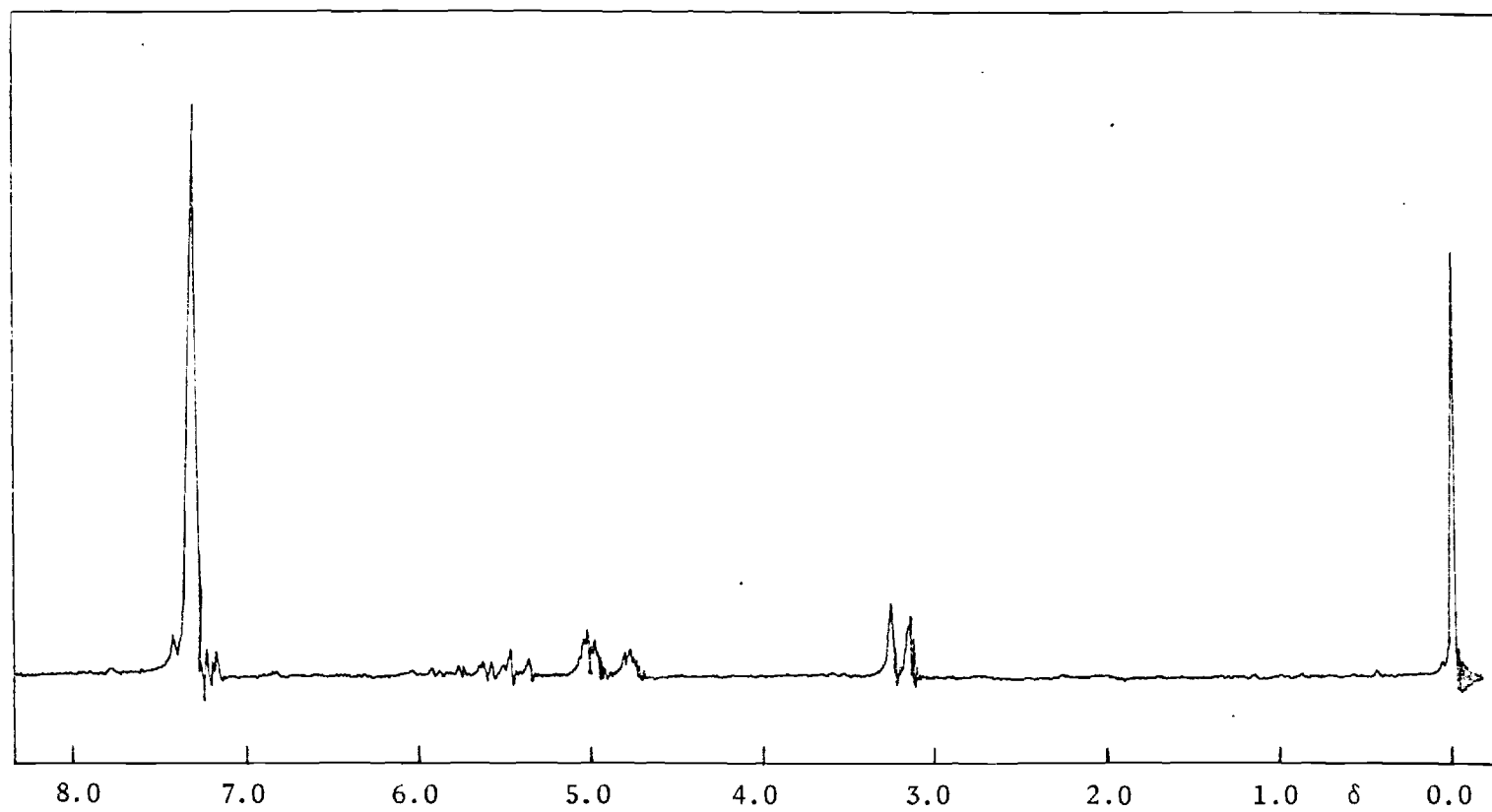
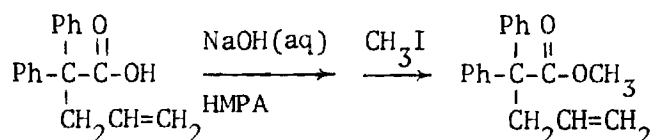


Figure 7. Nmr Spectrum (acetone- d_6) of 2,2-Diphenyl-4-pentenoic Acid (73-I)

added to the aqueous phase which was then acidified with HCl. The free organic acids were extracted with methylene chloride, and the extract was dried over anhyd CaCl_2 ; the solution was filtered and concentrated to a solid tan residue containing minor amounts ($\leq 5\%$) of starting material and two unknown components in addition to the major peak corresponding to alkylated product. The solid residue was dissolved in 95% ethanol to yield 17.7 g (27.1% yield) white crystals mp $140.0^\circ\text{--}142.0^\circ$ (reported mp $141.5^\circ\text{--}141.9^\circ$ for 2,2-diphenyl-4-pentenoic acid)⁶⁴ of 99% purity according to vpc. The nmr spectrum (acetone- d_6) had absorption at δ 3.21 (2.0 H, d, $J = 6.0$ Hz, $-\text{CH}_2\text{--CH=CH}_2$), 4.89 (2.0 H, complex d, $J = 14.0$ Hz, $-\text{CH=CH}_2$), 5.62 (1.3 H, complex m, $-\text{CH=CH}_2$), 7.3 (10.1 H, s, Ph_2 -), which was consistent with that expected for 2,2-diphenyl-4-pentenoic acid.

Synthesis of Methyl 2,2-Diphenyl-4-pentenoate⁶⁵ (50-II)



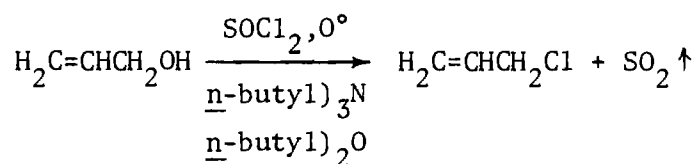
In a 50-ml flask was added 1.895 g (0.007 mole) of 2,2-diphenyl-4-pentenoic acid, 25 ml HMPA, and 1.5 ml 6.25 M NaOH. The mixture was stirred (via magnetic stirring bar) at room temperature overnight (solution was homogeneous after ca. 10 min) and then 1 ml (2.28 g or 0.016

64. R. T. Arnold and S. Searles, Jr., J. Amer. Chem. Soc., **71**, 1150 (1949).

65. A general alkylation method of free acids to give esters; J. E. Shaw, D. C. Kumerth, and J. T. Sherry, Tetrahedron Lett., 689 (1973).

mole) of methyl iodide was added and allowed to react for 2.5 hr at room temperature. The amber soln was then added to 60 ml of 5% HCl and extracted with ether. The ether extract was washed with water, dried over anhyd MgSO_4 , and concentrated to yield 2.10 g of crude ester of > 99% purity according to vpc.* The yield was quantitative.

Synthesis of Allyl Chloride^{54a} (126-I)

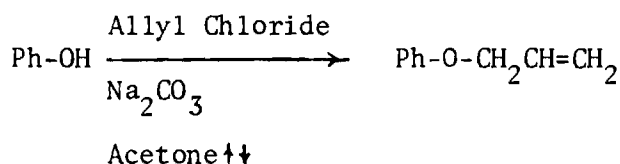


In a 300-ml 3-neck flask equipped with magnetic stirring bar, thermometer, and a double condensing trap was added 19.33 g (0.148 mole) freshly distilled n-butyl ether (dried over sodium wire, bp 136.0°) under nitrogen. After 38.90 g (0.210 mole) of tri-n-butylamine (freshly dried over KOH pellets) and 12.81 g (0.221 mole) of freshly distilled allyl alcohol (dried over molecular sieve, Linde, 4Å, bp 95.0°) was added, stirring was begun, and a wet ice bath added. When the contents of the flask reached 0° , 33.00 g (0.277 mole) of thionyl chloride was added dropwise over 1.5 hr so that the temperature of the reaction did not go above 10° . The reaction mixture gradually darkened until the final soln was a dark brown. The cooling bath was removed and stirring was continued at room temperature for 2.25 hr. With the double receiver traps cooled by Dry Ice-acetone, the nitrogen inlet was removed and a vacuum line attached. The reaction product was

*The retention time of the ester was identical with that of independently prepared methyl 2,2-diphenyl-4-pentenoate which had been prepared from the corresponding acid with CH_2N_2 .

distilled at 150 mm until the vapors reached 80°. The clear colorless distillate (90% condensed in the first trap) was washed carefully with 10% Na₂CO₃ until neutral or slightly basic to litmus. The neutral distillate was dried over molecular sieve (Linde, 4A) overnight and redistilled at 25°/150 mm to give 7.82 g for a yield of 46.2% (based on allyl alcohol) of pure product.

Synthesis of Allyl Phenyl Ether According to Claisen^{7a} (66-I)



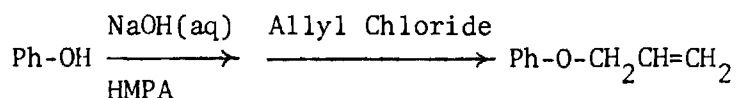
In a standard 2000-ml Morton apparatus was added 94.0 g (1.00 mole) of phenol, 120.0 g (1.132 g-formula wt) of Na₂CO₃, 150 g (1.00 g-formula wt) of NaI, and 500 ml of acetone. To this reaction mixture was added 81.0 g (1.06 mole) of allyl chloride over a 15 min period. Reflux was begun with slow stirring for 8.0 hr. The cream-yellow suspension was cooled; water and then ether were added. The ethereal extract was washed twice with 10% KOH, twice with water, and then dried over anhyd CaCl₂ overnight. The ether was removed and the crude oily product was vacuum distilled at 90.0°/3 mm to give 37.0 g (27.6% yield based on phenol) of > 95% purity allyl phenyl ether. The purified distillate was identical in vpc retention time with an authentic sample of commercial allyl phenyl ether.

A better yield (74-II) was obtained by a modified procedure⁶⁶ as follows: In a 500-ml 3-neck flask equipped with reflux condenser

66. L. I. Smith, H. H. Hoehn, and A. G. Whitney, J. Amer. Chem. Soc., **62**, 1863 (1940).

(with drying tube) and magnetic stirring bar was added 15.00 g (0.160 mole) of phenol, 26.50 g (0.160 g-formula wt) of KI, 24.00 g (0.174 g-formula wt) of K_2CO_3 , 100 ml of acetone, and 10 ml of water. Reflux was attained and 11.28 g (0.148 mole) of allyl chloride (neat) was added dropwise over a 10 min period. Reflux was continued for 9 hr and then the acetone was distilled. The residue was washed four times with 10% NaOH, three times with water, and then ether was added. The ether extract was dried over anhyd $MgSO_4$ overnight and was concentrated to give 15.31 g of crude oil product (77.0% yield based on phenol) which was distilled at 26.5° - $28.0^\circ/125\mu$ to give 14.28 g (71.8% yield) pure allyl phenyl ether according to vpc.

Synthesis of Allyl Phenyl Ether⁶⁵ (121-II)



In a 200-ml flask equipped with reflux condenser and magnetic stirring bar was added 13.91 g (0.148 mole) of phenol and 25 ml (0.156 g-formula wt) of 6.25 M NaOH with stirring to effect solution. To the sodium phenoxide soln was added 50 ml hexamethylphosphoramide (HMPA) with subsequent formation of a white precipitate within 1-5 min. Addition of 9.39 g (0.123 mole) of allyl chloride in 30 ml of acetone was completed in a 30 min period; and after another 30 min at room temperature, only a small amount of the white ppt remained in the flask. After the white ppt had disappeared completely (after 3 hr reaction) and the solution was refluxed for 30 min, the acetone was distilled. The distillate had the smell of allyl chloride and thus was recombined

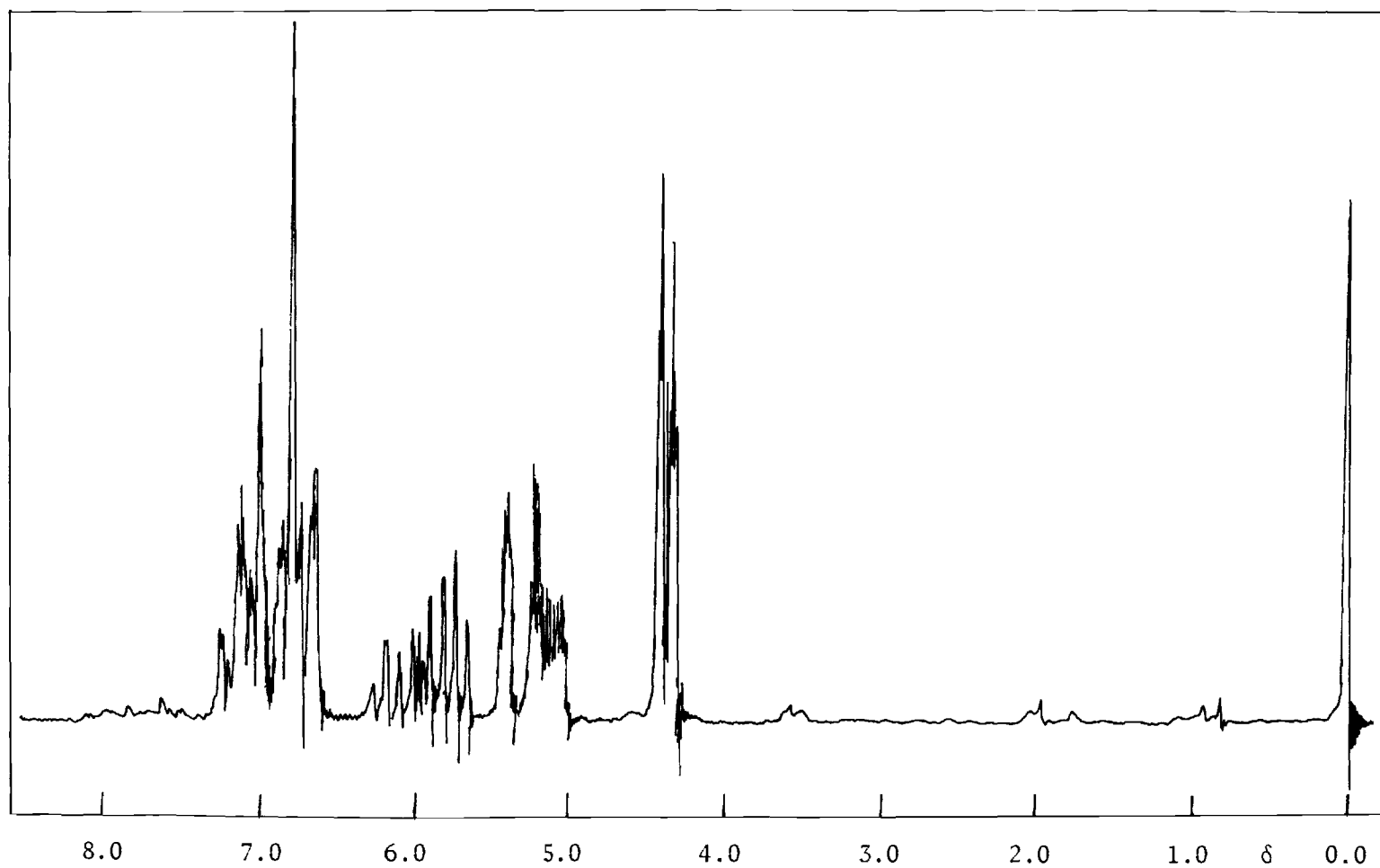
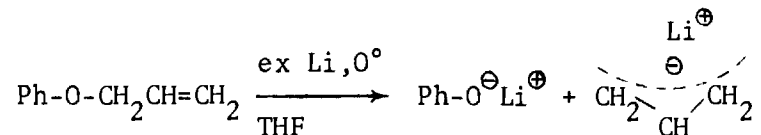


Figure 8. Nmr Spectrum (CS₂) of Allyl Phenyl Ether (121-II)

with the pot material and refluxed overnight. The reaction mixture was then distilled to remove the acetone and other volatile components. The pot residue (HMPA soln) was transferred to a separatory funnel and one volume of water and two volumes of ether was added. The ether extract was washed with 10% NaOH and then water until neutral to pH-Hydrion paper, dried over anhyd MgSO_4 , filtered, and condensed to give 18.90 g of a clear liquid. The product was vacuum distilled at bp $75.0^\circ\text{--}76.0^\circ/2\text{ mm}$ to give 13.74 g (83.3% yield) allyl phenyl ether of > 99% purity according to vpc. Vpc retention time and the nmr spectrum were identical to that of commercial allyl phenyl ether. Two other similar syntheses averaged 88.0% yield of pure product.

Synthesis of Allyllithium⁶⁷ (79-I)

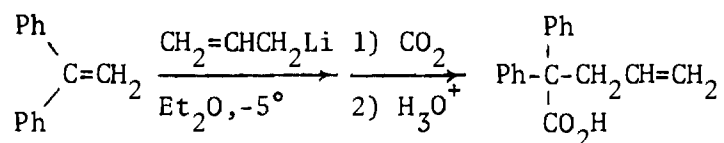


In a standard 1000-ml Morton apparatus was condensed 350 ml of tetrahydrofuran (THF) after which 9.14 g (1.32 g-atom) of freshly cut lithium wire was added. The flask was cooled to $-5^\circ \pm 5^\circ$ and 14.89 g (0.111 mole) allyl phenyl ether in 85 ml anhyd ether was added over a 30 min period with vigorous stirring. A slight pale purple-blue color developed within 5 min and reaction was observed on the lithium metal surface as was indicated by the formation of a yellow color which was repeatedly washed off by the stirred soln. Continued reaction resulted in an orange soln after 30 min at 0° and then 30 min at room

67. J. J. Eisch and A. M. Jacobs, J. Org. Chem., 28, 2145 (1963).

temperature. Double Gilman titration⁶⁸ (phenolphthalein end-point) indicated a minimum of 0.0693 equivalents of allyllithium present for a 62.5% yield based on starting ether. The fresh allyllithium soln was kept at 0° and was used subsequently.^{69,70}

Synthesis of 2,2-Diphenyl-5-hexenoic Acid (79-I)



In a standard 1000-ml Morton apparatus was prepared 0.0693 equivalents of fresh allyllithium. To the orange soln was added 13.83 g (0.077 mole) of 1,1-diphenylethene (neat) in 15 ml ether at $-5^\circ \pm 5^\circ$ over a 10 min period. The reaction soln turned red immediately with the first drop of hydrocarbon and was a black-blood red on completion of the addition. Stirring was continued 15 min at 0° and then the solution was jetted onto excess crushed Dry Ice and allowed to stand overnight. The acidic salts were washed with ether, acidified with hydrochloric acid and extracted with ether to give a crude acidic reaction product containing ca. 20% phenol and ca. 80% relative yield of a carboxylic acid according to vpc. Additional washing of the

68. H. Gilman and A. H. Haubein, J. Amer. Chem. Soc., 66, 1515 (1944).

69. Alternative methods of the synthesis of allylic lithium reagents have been reported by (a) G. Courtois and L. Migniac, J. Organometal. Chem., 69, 1 (1974); (b) J. A. Katzenellenbogen and R. S. Lenox, Tetrahedron Lett., 1471 (1972).

70. The method used to prepare allyllithium produces a minor by-product, propiophenone ($\leq 5\%$), by way of a dianion intermediate. D. R. Dimmel and S. B. Gharpure, J. Amer. Chem. Soc., 93, 3991 (1971).

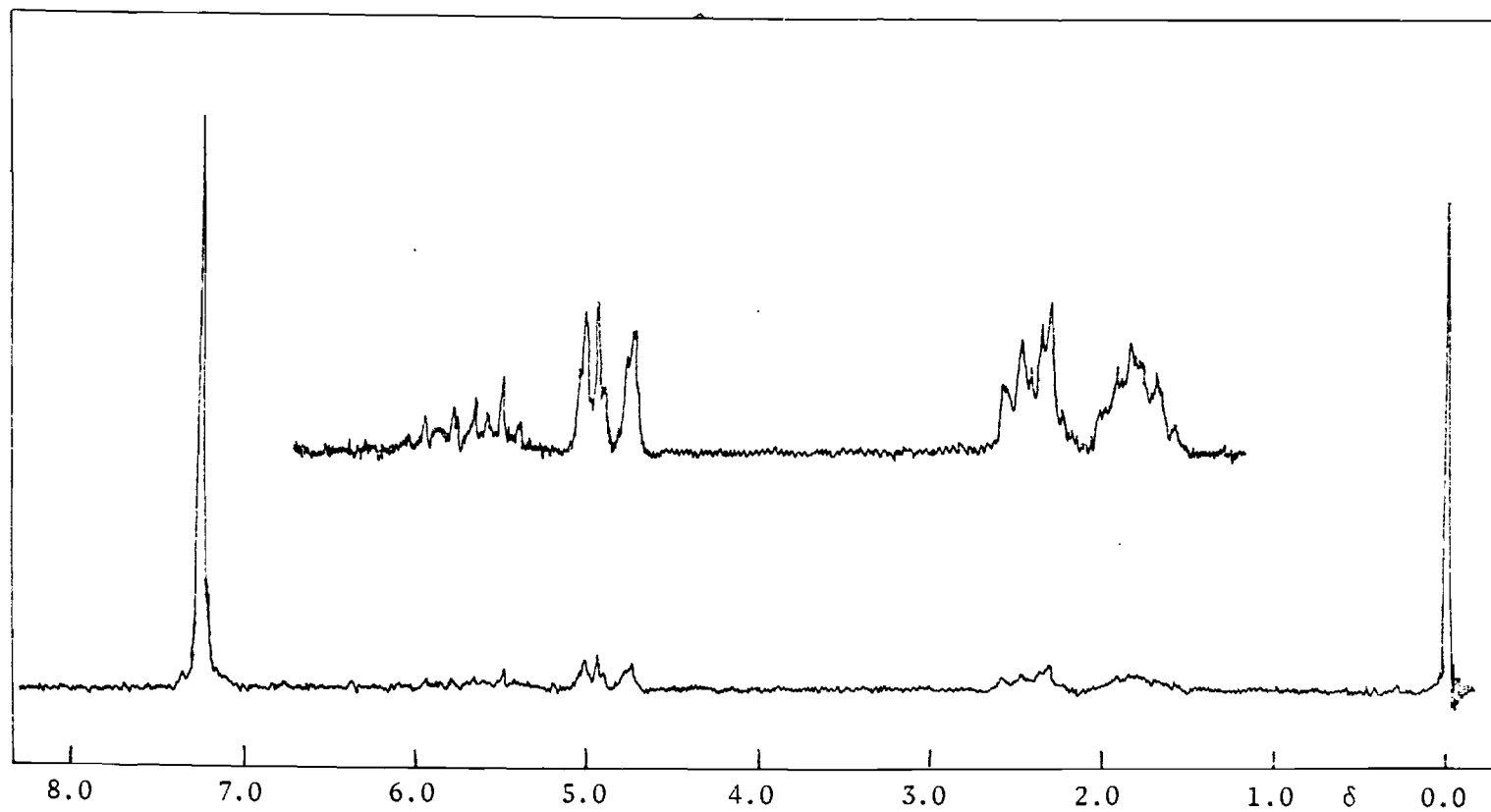


Figure 9. Nmr Spectrum (CCl_4) of 2,2-Diphenyl-5-hexenoic Acid (79-1)

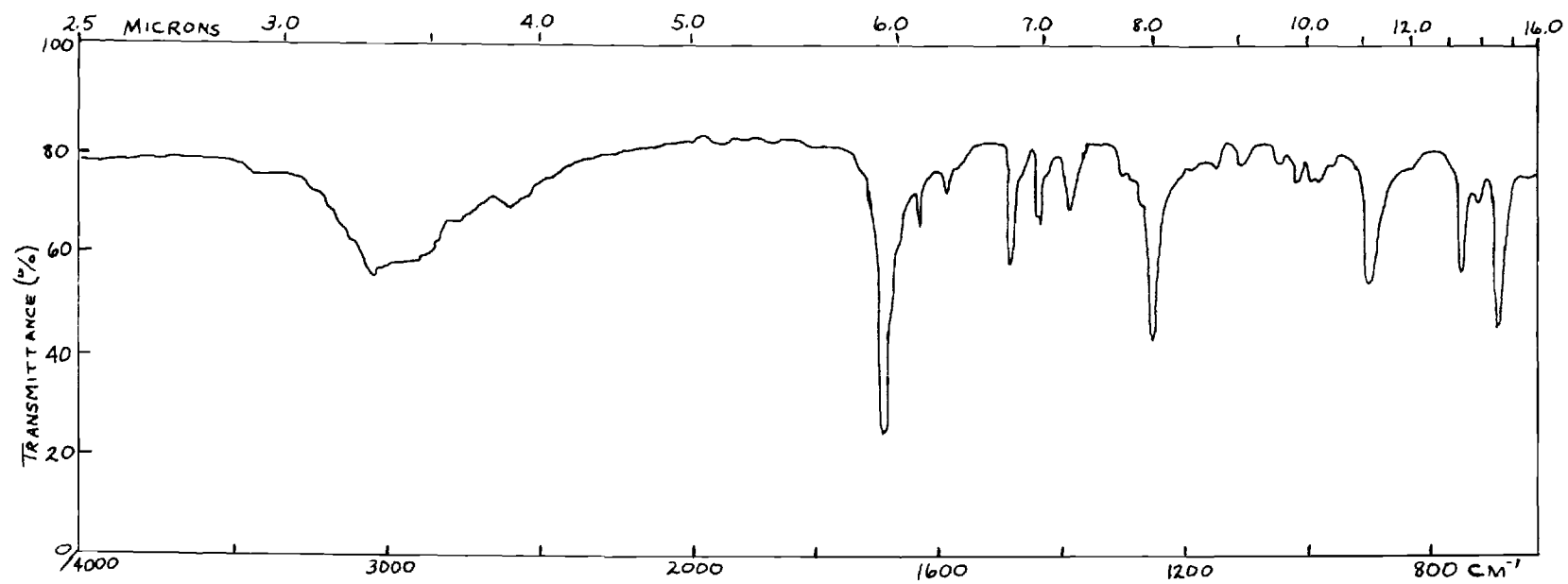


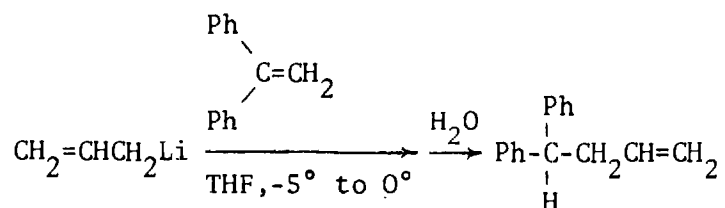
Figure 10. Infra-red Spectrum (KBr pellet) of 2,2-Diphenyl-5-hexenoic Acid (79-I)

etherate with water and crystallization of the acid from 95% ethanol gave 3.47 g (18.9% yield based on allyllithium) of carboxylic acid of > 99% purity with mp 138.0°-139.0°. The nmr spectrum (CCl₄) had absorption at δ 1.50-2.70 (4.0 H, complex m, -CH₂CH₂-), 4.60-6.10 (3.4 H, complex m, -CH=CH₂), 7.23 (10.2 H, s, Ph₂-), which was consistent with that expected for 2,2-diphenyl-5-hexenoic acid. The mass spectrum (Varian) of the free acid gave ions at 266 (2,M+), 211 (34), 213 (15), 212 (86), 211 (22), 194 (21), 180 (19), 179 (22), 178 (25), 167 (71), 166 (40), 165 (100), 152 (18), 143 (17), 118 (16), 117 (55), 115 (19), 105 (30), 103 (37), 91 (87), 77 (45), 55 (15), 41 (15), 39 (19).

Anal. (Galbraith) Calcd for C₁₈H₁₈O₂: C, 81.15; H, 6.83.

Found: C, 81.35, 81.27; H, 6.79, 6.88.

Synthesis of 5,5-Diphenyl-1-pentene (91-I)



In a standard 1000-ml Morton apparatus was prepared allyllithium according to the previous method from 9.14 g (1.317 g-atom) of lithium wire and 14.74 g (0.110 mole) of allyl phenyl ether. (A Gilman titration was not carried out.) Addition of 12.47 g (0.069 mole) of 1,1-diphenylethene (neat) over a 5 min period resulted in a blood-red soln. After stirring the reaction mixture for 1.5 hr, ca. 60 drops of water was required to completely destroy the red color while additional water was added to decompose the excess lithium metal.

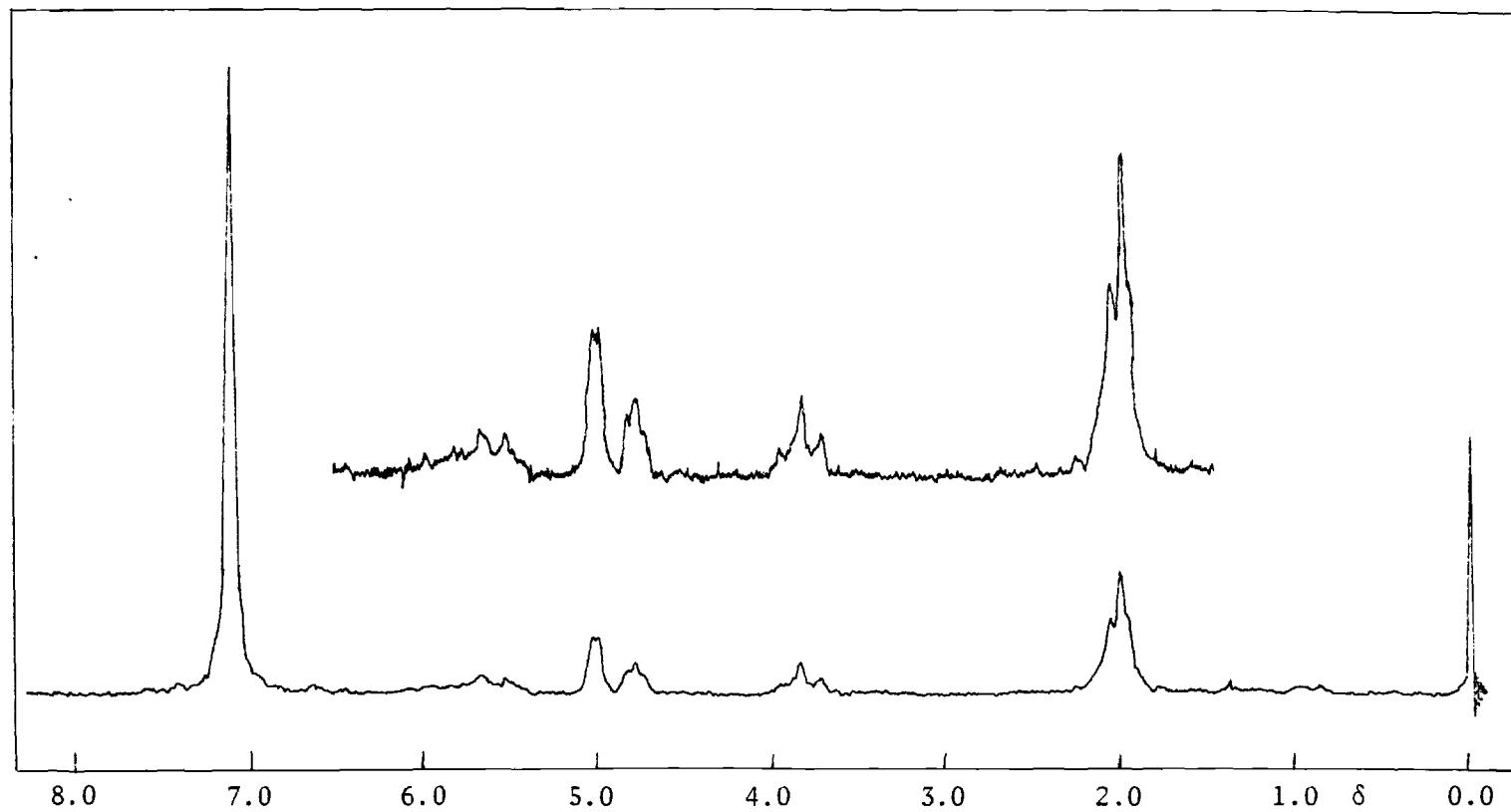
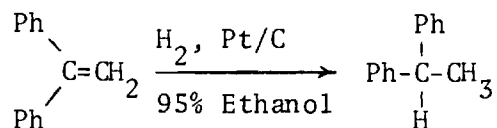


Figure 11. Nmr Spectrum (CCl_4) of 5,5-Diphenyl-1-pentene (91-I)

The mixture was allowed to stand overnight and workup was accomplished by separating the THF layer from the basic aqueous layer and further extracting the organic material from the aqueous with ether. The ethereal THF solution was dried over CaCl_2 and concentrated to give 25.15 g of a crude oil. Distillation of the crude oil through a 12" ss spinning-band column removed the majority of the phenol while further distillation of the pot residue on a Hickman still resulted in the collection at $100.0^\circ\text{--}105.0^\circ/4\text{ mm}$ of 11.5 g (74.7% yield based on starting hydrocarbon) of product of 98% purity according to vpc. The nmr spectrum (CCl_4) had absorption at δ 2.03 (3.7 H, m, $-\text{CH}_2-\text{CH}_2-$), 3.85 (0.9 H, t, $J = 7.5\text{ Hz}$, $\text{Ph}_2-\text{CH}-$), 4.70-6.10 (3.0 H, complex m, $-\text{CH}=\text{CH}_2$), 7.12 (10.0 H, s, Ph_2-), which was consistent with that expected for 5,5-diphenyl-1-pentene. The mass spectrum (Varian) gave ions at 182 (25), 181 (100), 166 (18), 165 (22), 103 (31), 77 (16), but no observable 222 ion (M^+).

Anal. (Galbraith) Calcd for $\text{C}_{17}\text{H}_{18}$: C, 91.84; H, 8.16. Found: C, 91.63, 91.73; H, 8.32, 8.36.

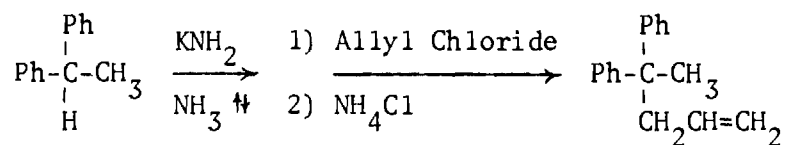
Synthesis of 1,1-Diphenylethane (109-I)



Parr hydrogenation of 23.20 g (0.129 mole) of 1,1-diphenylethene with 1.01 g 5% Pt/C in 100 ml 95% ethanol at room temperature for 3.5 hr proceeded with a 97% theoretical uptake of hydrogen. The crude reaction product according to qualitative vpc contained 3.0% diphenylmethane, 94.0% 1,1-diphenylethane, and 3.0% of an unidentified compound.

Distillation at 63.0°-65.0°/140 μ gave ca. 25 g of 1,1-diphenylethane of 96.6% purity (3.4% impurity was of longer retention time and was not identified) for a 96% absolute yield.

Synthesis of 4,4-Diphenyl-1-pentene (110-I)



In a standard 1000-ml Morton apparatus was condensed 400 ml of ammonia. Potassium amide was made from 4.39 g (0.112 g-atom) of potassium metal. To the KNH₂ soln (at reflux) was added 15.82 g (0.087 mole) of 1,1-diphenylethane in an equal volume of anhyd ether over a 10 min period. The solution developed a red color immediately on addition of the hydrocarbon, was stirred for 5 min longer, and quenched by addition of 9.03 g (0.118 mole) of allyl chloride in two volumes of anhyd ether over a 10 min period. The mixture was stirred an additional 3 min and then the excess KNH₂ was quenched with NH₄Cl. The cream-colored soln was allowed to stand overnight as the ammonia evaporated in the hood. The product was worked up by ether extraction of the aqueous layer, removal of the interphase material by filtration of the ether extract, and drying of the etherate over anhyd MgSO₄ overnight. The ethereal solution was concentrated to give 19.17 g of crude oil which was distilled at 88.0°-90.0°/80 μ to yield 10.0 g of 4,4-diphenyl-1-pentene (52% absolute yield) of 99.5% purity by vpc. The nmr spectrum (CCl₄) had absorption at δ 1.53 (3.0 H, s, -CH₃), 2.82 (1.9 H, d, J = 6.0 Hz, -CH₂-CH=CH₂), 4.67-5.83 (3.1 H, m, -CH=CH₂),

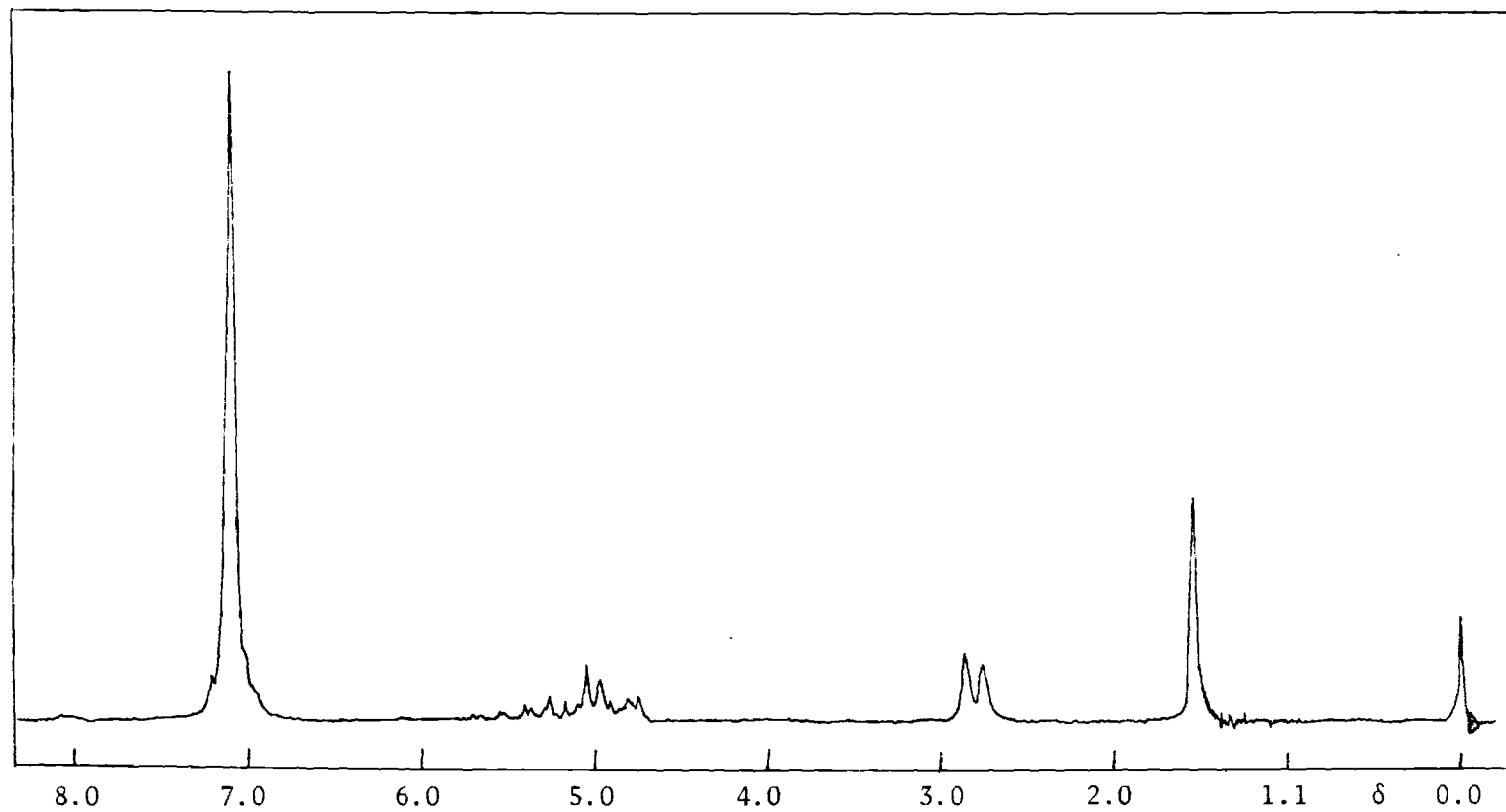
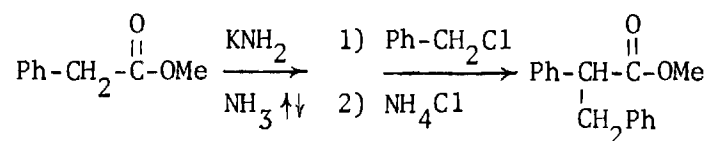


Figure 12. Nmr Spectrum (CCl_4) of 4,4-Diphenyl-1-pentene (110-I)

7.10 (10.0 H, s, Ph_2 -), which was consistent with that expected for 4,4-diphenyl-1-pentene. The mass spectrum (Varian) gave ions at 182 (35), 181 (100), 179 (12), 178 (12), 166 (24), 165 (34), 103 (43), 91 (10), 77 (19) and no observable ion at 222 (M^+).

Anal. (Galbraith) Calcd for $\text{C}_{17}\text{H}_{18}$: C, 91.84; H, 8.16. Found: C, 91.61, 91.59; H, 8.23, 8.33.

Synthesis of Methyl 2,3-Diphenylpropionate⁷¹ (30-II)



In a standard 1000-ml Morton apparatus was condensed 500 ml of ammonia. Potassium amide was made from 7.97 g (0.204 g-atom) of potassium metal. To the KNH_2 soln (at reflux) was added 26.55 g (0.177 mole) of freshly distilled (bp 216.0° - 218.0°) methyl phenylacetate in 25 ml anhyd ether over a 10 min period. The soln was stirred for 15 min at reflux (reaction mixture developed a slight color which disappeared on complete addition of ester) after which 25.85 g (0.204 mole) of freshly distilled (bp 175.5° - 176.5°) benzyl chloride in 25 ml anhyd ether was added over a 10 min period. Stirring at reflux was continued for 1 hr as the reaction mixture became a cloudy brownish-gray. Excess KNH_2 (if any) was quenched by addition of NH_4Cl and the white mixture was allowed to stand as the ammonia evaporated in the hood. The reaction product was extracted by ether,

71. W. G. Kenyon, E. M. Kaiser, and C. R. Hauser, J. Org. Chem., **30**, 2937 (1965) for a general procedure.

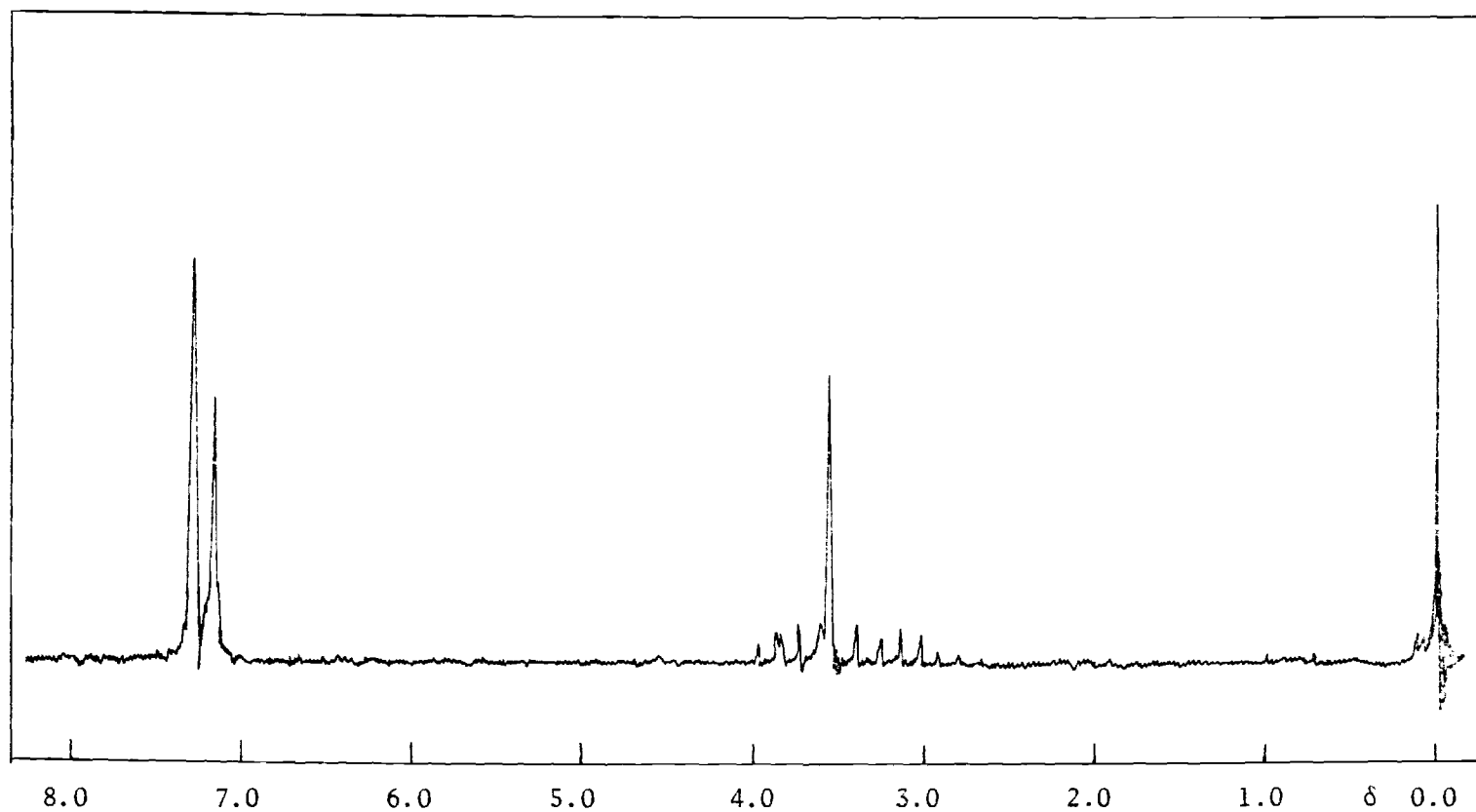
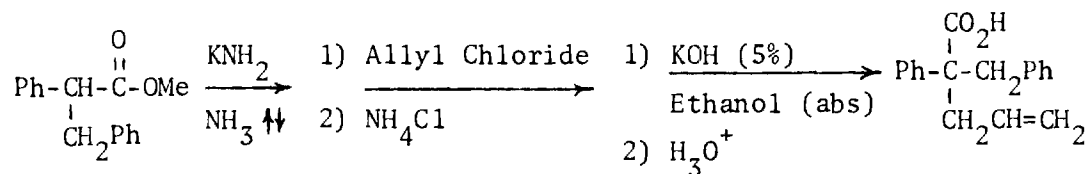


Figure 13. Nmr Spectrum ($\text{CCl}_4\text{-CDCl}_3$) of Methyl 2,3-diphenylpropionate (30-II)

dried over Drierite, and concentrated to give 45.84 g of an oil which was shown (qualitative vpc) to be the desired product of 95% purity. The oil was distilled at 98.0°-100.0°/40μ and gave 29.96 g (70.5% based on starting ester) of > 99% purity. The nmr spectrum (CCl₄-CDCl₃) had absorption at δ 2.78-4.00 (2.6 H, m, Ph-CH(CH₂Ph)-CO₂Me), 3.56 (3.0 H, s, -OCH₃), 7.10-7.35 (10.5 H, m centered at 7.20δ, Ph₂-), which was consistent with that expected for methyl 2,3-diphenylpropionate.* No elemental analysis was carried out.

Synthesis of 2-Benzyl-2-phenyl-4-pentenoic Acid** (34-II)



In a standard 1000-ml Morton apparatus was condensed 500 ml of ammonia. Potassium amide was made from 6.18 g (0.158 g-atom) of potassium metal. To the KNH₂ soln (ca. -50°) was added 30.0 g (0.125 mole of methyl 2,3-diphenylpropionate (followed by addition of 25 ml anhyd ether) over a 10 min period. The reaction mixture was stirred 20 min but some of the ester had frozen and had not reacted; therefore, another 25 ml anhyd ether was added and the mixture stirred another 30 min to give a wine-red homogeneous soln. Then 14.09 g (0.184 mole) of allyl chloride in 15 ml anhyd ether was added over a 15 min period at reflux. Stirring at reflux was continued for 1 hr and then to the

*The alkyl protons were unique due to the fact of the asymmetry at carbon 2.

**Prepared according to the general procedure of reference 71.

brownish solution was added 14.9 g (0.355 g-formula wt) of NH_4Cl .

The ammonia was allowed to evaporate overnight and the crude ethereal solution (> 95% vpc purity) was concentrated to 29.44 g of material. The crude product was dissolved in excess hot acetone and concentrated to ca. 25 ml total soln, cooled, and the crystals (3.1 g) which formed were filtered and dried (mp 128.0° - 128.5°). A second crop of crystals (1.10 g) had a mp 128.0° - 129.0° . The nmr spectrum of the methyl ester was not recorded.

Anal. (Atlantic) Calcd for $\text{C}_{19}\text{H}_{20}\text{O}_2$: C, 81.40; H, 7.19. Found: C, 81.01; H, 6.88.

To the mother liquor (23.56 g) which was essentially all desired ester, was added 100 ml of 5% KOH in 95% ethanol and was refluxed over the weekend (93 hr). The reaction mixture was cooled and concentrated. Water was added and the neutral material extracted with ether to yield 5.45 g of unreacted ester. The aqueous layer was acidified with HCl and extracted with ether to give 16.75 g (74.8% yield based on starting ester) of crude acid. Crystallization of the acid from pentane gave 9.11 g of acid, mp 85.5° - 87.0° . The nmr spectrum (CS_2) had absorption at δ 2.68 (1.8 H, d, $J = 7.0$ Hz, $-\text{CH}_2-\text{CH}=\text{CH}_2$), 3.27 (1.9 H, s, $\text{Ph}-\text{CH}_2-$), 4.90-6.00 (3.2 H, m, $-\text{CH}=\text{CH}_2$), 6.71-7.40 (10.0 H, complex m, Ph_2-), 12.04 (1.0 H, s, $-\text{COOH}$), which was consistent with that expected for 2-benzyl-2-phenyl-4-pentenoic acid. The mass spectrum (Varian) of the free acid gave ions at 266 (15, M^+), 225 (9), 181 (7), 179 (8), 178 (9), 175 (23), 131 (13), 129 (43), 115 (8), 107 (13), 103 (8), 92 (10), 91 (100), 77 (13).

Anal. (Atlantic) Calcd for $\text{C}_{18}\text{H}_{18}\text{O}_2$: C, 81.18; H, 6.81. Found:

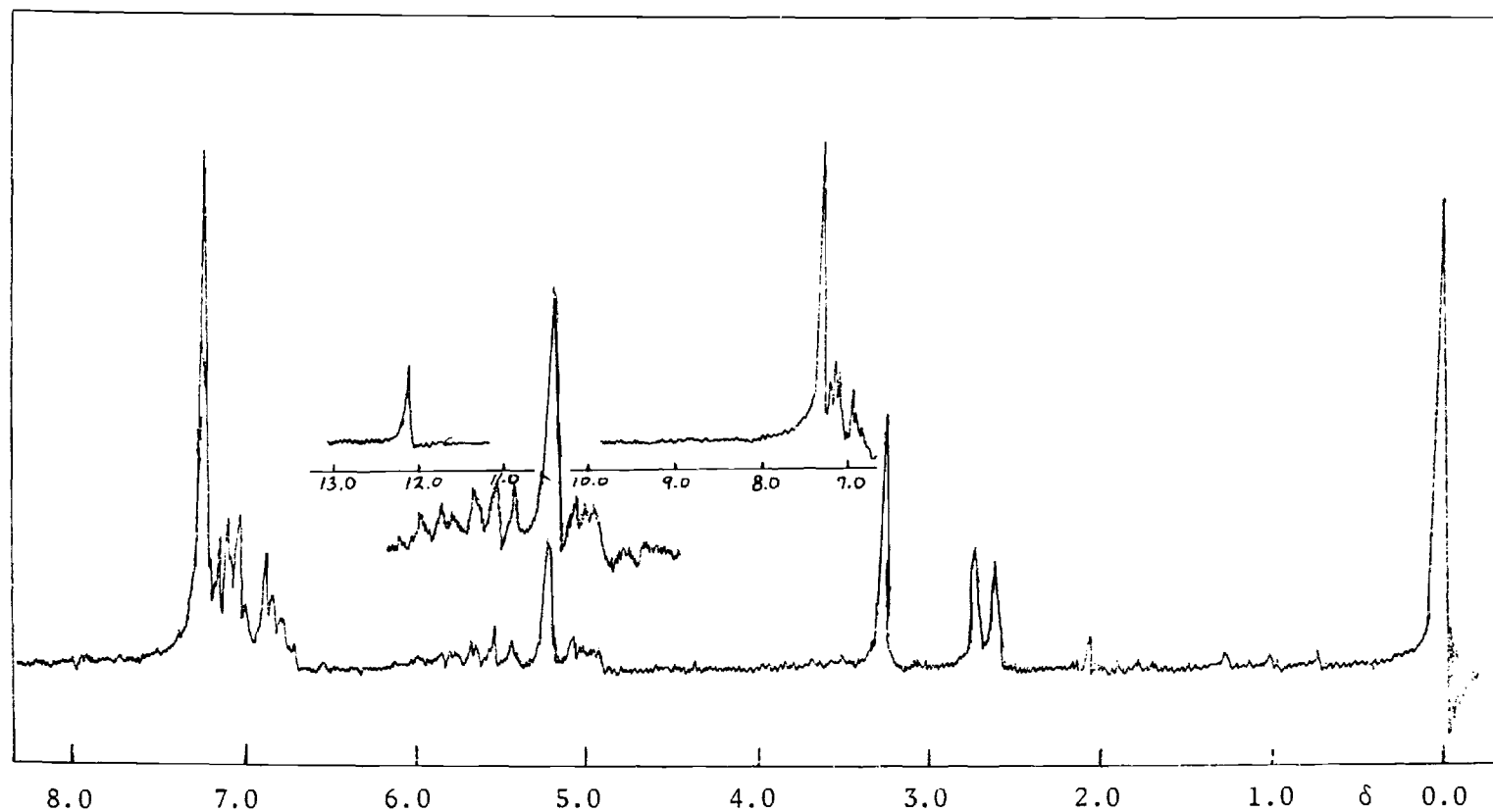


Figure 14. Nmr Spectrum (CS_2) of 2-Benzyl-2-phenyl-4-pentenoic Acid (34-II)

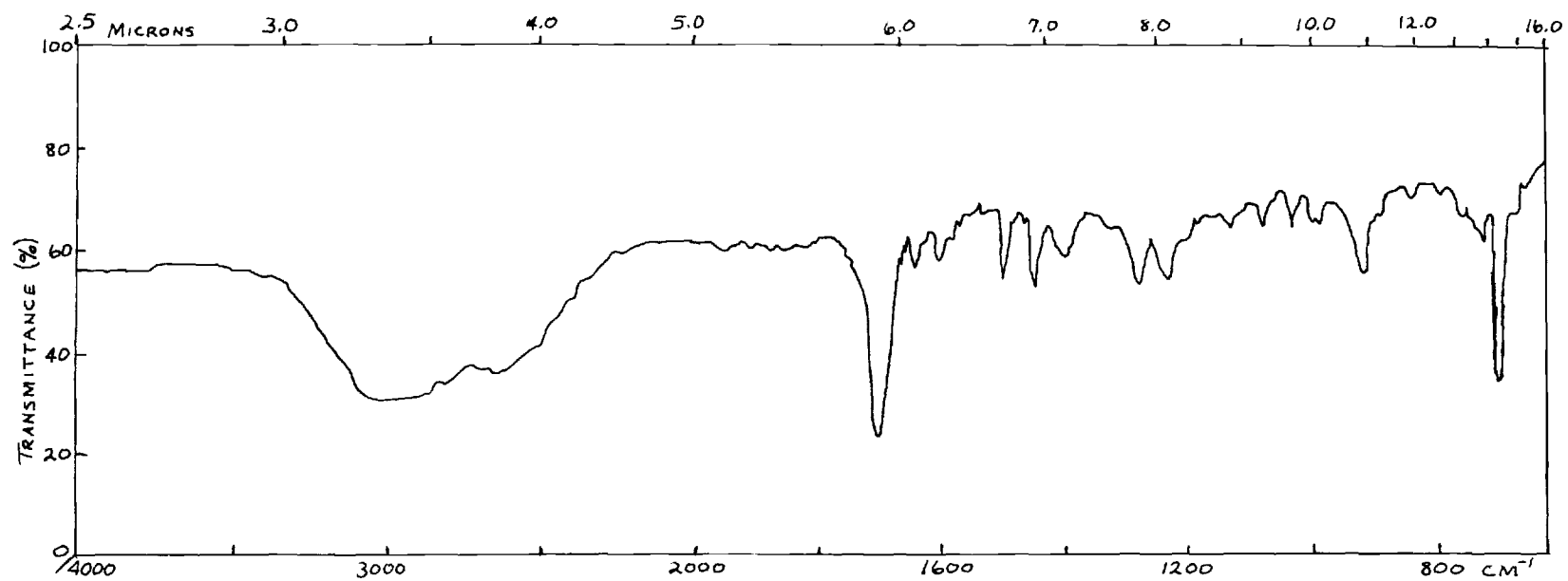
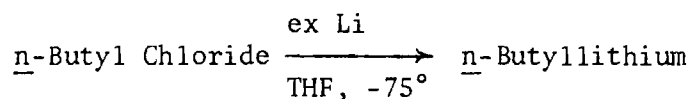


Figure 15. Infra-red Spectrum (KBr pellet) of 2-Benzyl-2-phenyl-4-pentenoic Acid (34-II)

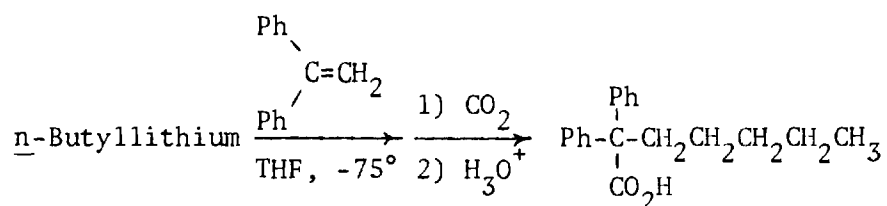
C, 81.03; H, 6.90.

Synthesis of *n*-Butyllithium (60-II)



In a 500-ml Morton apparatus⁷² was condensed 250 ml THF and then 15.38 g (2.216 g-atom) of lithium wire was added. To the THF was added 1 ml (2.28 g, 0.016 mole) of methyl iodide and the flask was cooled to -78° at which time 36.77 g (0.397 mole) of *n*-butyl chloride (freshly distilled, bp 76.0° - 77.0°) was added rapidly and stirred for 3 hr. A 1-ml sample of the yellowish-green solution was quenched and titrated with 1.0005 N HCl (phenolphthalein end-point). The organo-lithium sample taken required 1.15 ml acid and therefore contained 0.287 equivalents of *n*-butyllithium (72.3% yield).

Synthesis of 2,2-Diphenylheptanoic Acid (86-II)



In a modified 500-ml Morton flask was condensed 250 ml THF and then the flask was cooled to -78° and 50 ml of commercial *n*-butyllithium in pentane was added. A 5-ml aliquot was hydrolyzed and the solution was shown to contain ca. 0.071 equivalents of *n*-butyllithium.

72. A bronze stirrer assembly with ss stirrer rather than an all ss assembly was used.

To the organolithium soln was added 10.36 g (0.058 mole) of 1,1-diphenylethene in 10 ml anhyd ether over a 15 min period. The resulting blood-red solution was stirred for 30 min and then forced onto excess crushed Dry Ice and allowed to stand overnight. Evaporation of the THF and then addition of water and ether resulted in separation of neutral from acidic material. The aqueous layer was acidified with HCl and extracted with ether. The ethereal extract was dried over anhyd MgSO_4 , concentrated, and cooled. The glassy residue began to crystallize and the residual ether was removed under vacuum at rm temp. The crude crystalline product was dissolved in hot 95% ethanol and cooled to 0° to effect crystal formation. The crystals were separated by filtration, washed with cold 95% ethanol, and dried to give 9.10 g of an acid mp 102.0° - 104.0° (reported mp 104.0° - 105.0°).⁷³ A second and third crop of crystals gave a combined yield of 12.57 g (77.4% absolute yield) of 2,2-diphenylheptanoic acid. Recrystallization from cyclohexane gave acid crystals of mp 104.0° - 105.0° . The nmr spectrum (CS_2) had absorption at δ 0.63-1.17 (8.7 H, m, $-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$), 2.03-2.40 (1.6 H, m, $-\text{CH}_2-$), 7.22 (10.0 H, s, Ph_2-), 11.82 (0.9 H, s, $-\text{CO}_2\text{H}$), which was consistent with that expected for 2,2-diphenylheptanoic acid.

73. M. H. Cauquil, M. J. Rouzaud, and M. M. Klepine, Academic Sciences, 9, October, 699 (1950); (b) K. Ziegler, F. Crossmann, H. Kleiner, and O. Schafer, Justus Liebigs Ann. Chem., 473, 1 (1929); (c) 7,7-diphenylheptanoic acid has also been reported with mp 104.0° - 105.0° by M. H. Cauquil, M. J. Rouzaud, R. E. Lyle, H. L. Fielding, and G. G. Lyle, Bull. Soc. Chim. Fr., 513 (1955) and R. T. Conley and B. E. Nowak, J. Org. Chem., 27, 1965 (1962).

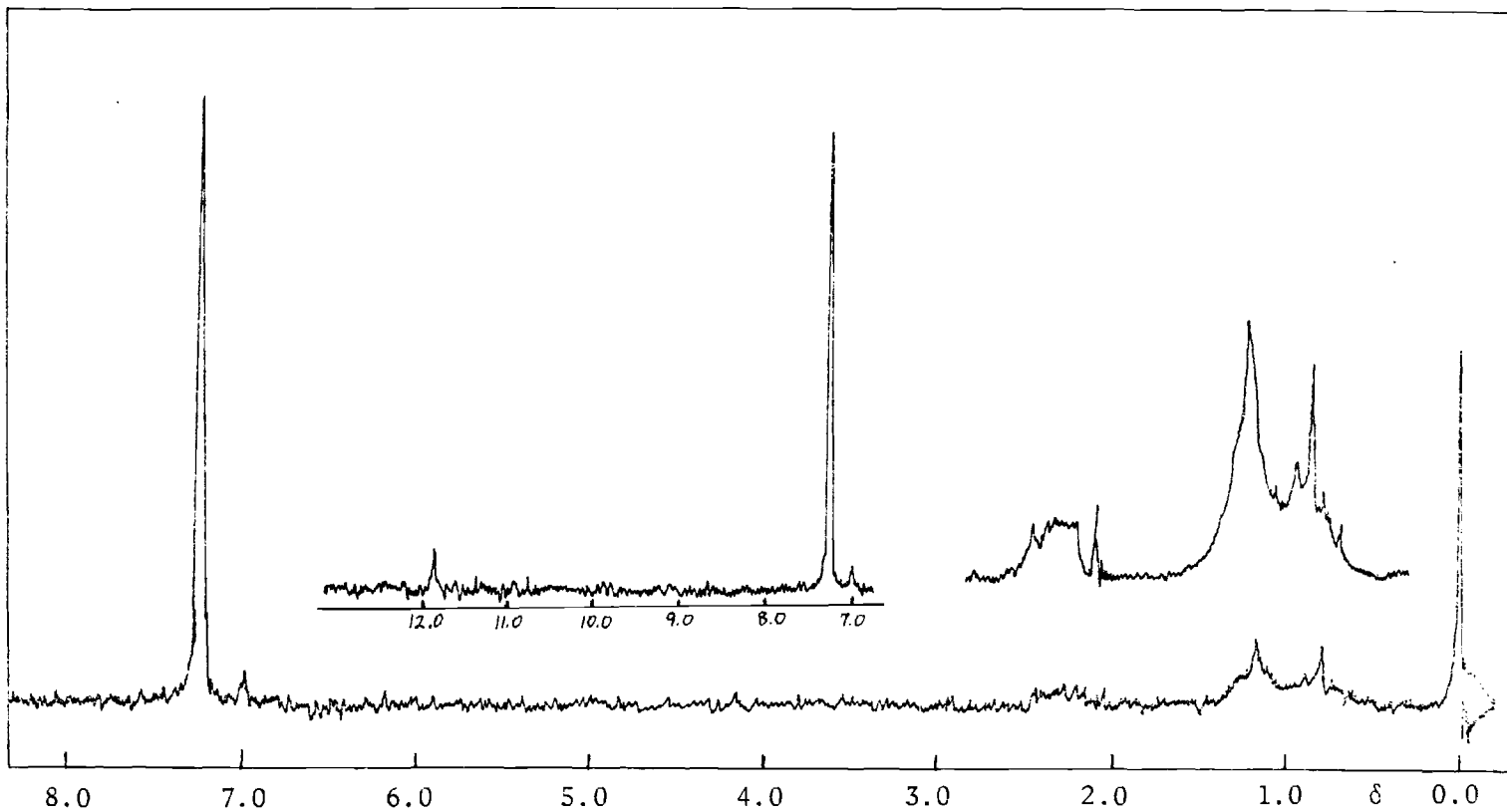


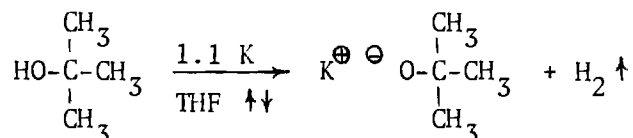
Figure 16. Nmr Spectrum (CS_2) of 2,2-Diphenylheptanoic Acid (86-II)

Anal. (Atlantic) Calcd for $C_{19}H_{22}O_2$: C, 80.82; H, 7.85. Found: C, 80.88, 80.85; H, 7.83, 7.85.

An earlier attempt (56-II) at the above synthesis of 2,2-diphenylheptanoic acid at 0° was unsuccessful. In a 500-ml flask was added 11.55 g (0.064 mole) of 1,1-diphenylethene (neat) to 25 ml of anhyd ether and the flask was then cooled to 0° . Addition of 20 ml (0.073 equivalents according to titration) of commercial n-butyllithium resulted in a blood-red soln which was allowed to react for 15 min after which time excess crushed Dry Ice was added and the mixture was allowed to stand overnight. The acid was worked up (7.66 g neutral material recovered) to give 5.78 g of crude acid (32.02% yield based on starting hydrocarbon) product. Recrystallization from 95% ethanol gave an acid of mp 172.0° - 173.0° . The nmr spectrum (CS_2) had absorption at δ 0.30-1.20 (11.6 H, m, $-\underline{CH}_2 \underline{CH}_2 \underline{CH}_2 \underline{CH}_2 \underline{CH}_3$) a 3.43 (2.0 H, s, $-C(Ph)_2-\underline{CH}_2-C(Ph)_2$), 6.50-7.50 (20.4 H, complex m centered at 7.00 δ), 10.94 (0.7 H, s, $-\underline{CO}_2H$), which was consistent with that expected for 2,2,4,4-tetraphenylnonanoic acid.

Anal. (Atlantic) Calcd for $C_{33}H_{34}O_2$: C, 85.68; H, 7.41. Found: C, 84.42, 84.37; H, 7.60, 7.62.

Preparation of Potassium tert-Butoxide (94-II)



In a standard 500-ml Morton apparatus (bronze housing) was condensed 250 ml THF. The addition of 9.30 g (0.238 g-atom) of

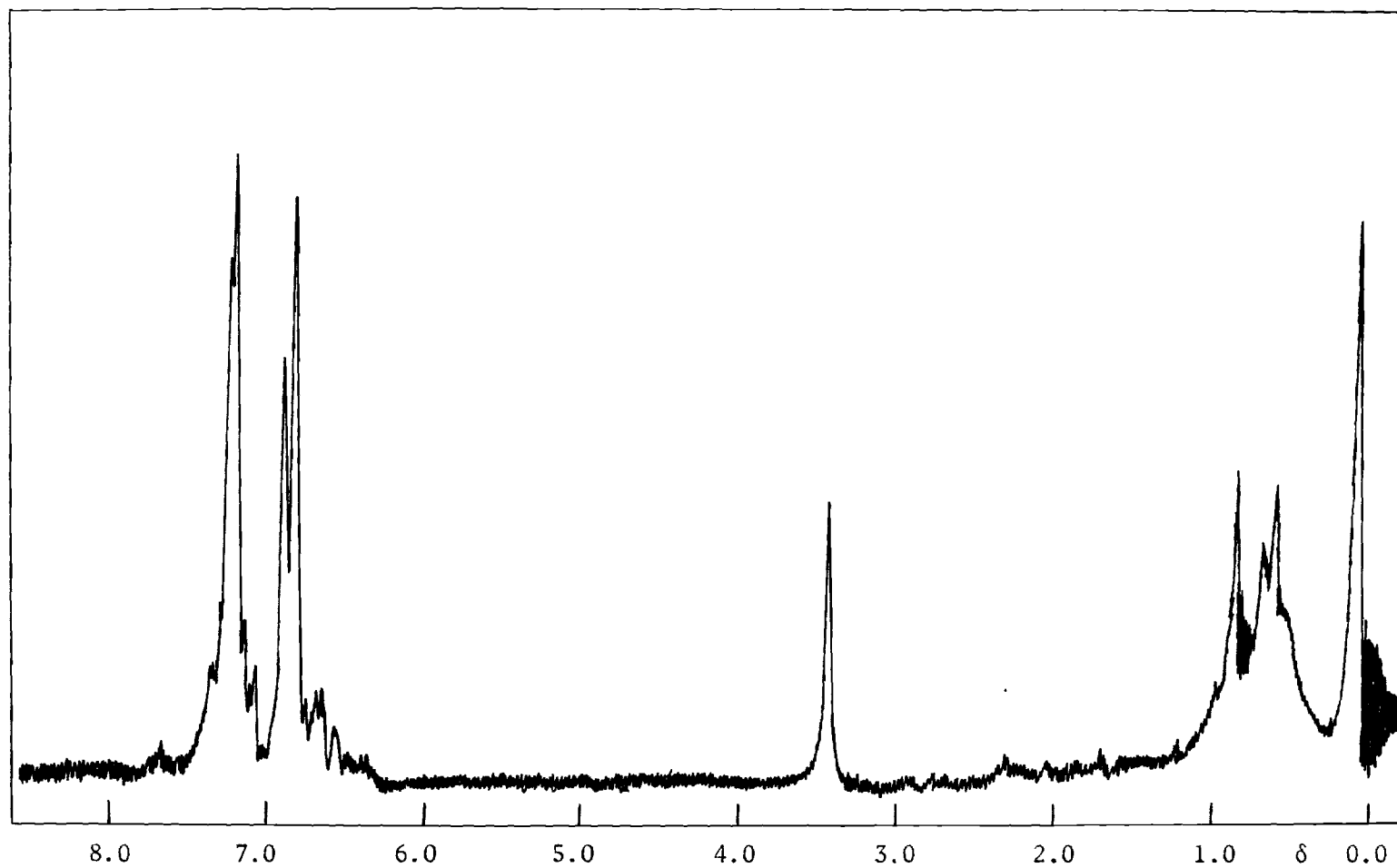
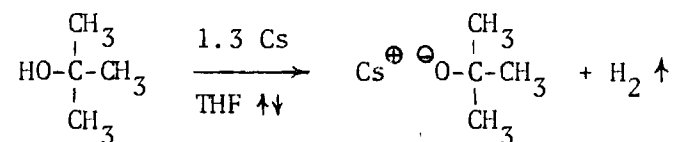


Figure 17. Nmr Spectrum (CS₂) of 2,2,4,4-Tetraphenylnonanoic Acid (56-II)

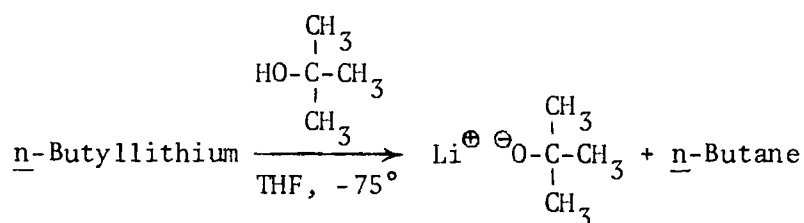
potassium metal was followed by reflux for 30 min and then was cooled to room temperature at which time 14.92 g (0.201 mole) of tert-butyl alcohol was added over a 15 min period (exothermic reaction with H₂ evolution). Continued stirring and reflux for 2 hr resulted in a homogeneous solution of potassium tert-butoxide.

Preparation of Cesium tert-Butoxide (94-II)



In a standard 500-ml Morton apparatus (in a Dry Box) was condensed 250 ml THF. Addition of 27.58 g (0.207 g-atom) of cesium metal followed by dropwise addition of 11.94 g (0.161 mole) of tert-butyl alcohol gave a straw-colored soln which changed to a greenish-brown after reflux for 2 hr. The soln was cooled (room temperature) and used immediately.

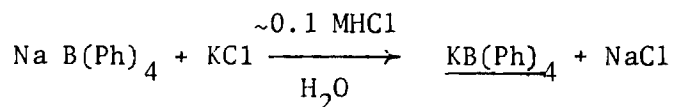
Preparation of Lithium tert-Butoxide (60-II)



In a standard 500 ml Morton apparatus (bronze housing) was condensed 250 ml THF. A fresh solution of n-butyllithium was made from 15.38 g (2.216 g-atom) of lithium wire and 36.78 g (0.397 mole) of n-butyl chloride to give a minimum of 0.287 equivalents according

to a double Gilman titration. To the organolithium soln was added 23.56 g (0.318 mole) of tert-butyl alcohol at -75° . The soln became milky and further stirring for 1.5 hr resulted in a gray suspension (Li metal particles).

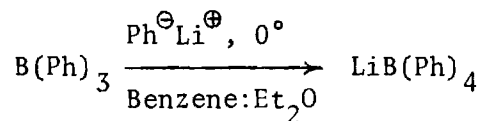
Synthesis of Potassium Tetraphenylborate⁷⁴ (102-II)



To an 1000-ml Erlenmeyer flask containing 150 ml of water at room temperature was added 11.88 g (0.035 mole) of sodium tetraphenylborate. The soln was filtered and to the filtrate was added 15 ml of 1.0 N HCl, followed by the addition of 6.62 g (0.089 g-formula wt) of KCl. The thick finely divided white suspension was allowed to stand for 15 min to facilitate ppt formation after which the suspension was separated by filtration with suction, washed with water, and air-dried overnight. The solid residue was broken up into a powder, heated for 7 hr at 100.0° , and then further dried in a desicator under vacuum for 24 hr at room temperature to give 10.64 m (85.67% yield based on NaBØ4) of powdery potassium tetraphenylborate (did not decompose at 345.0°).

74. (a) H. Flaschka and A. J. Barnard, Jr., Advances in Analytical Chemistry and Instrumentation, 1, 1 (1960); (b) I. M. Kolthoff, E. B. Sandell, E. J. Meehan, S. Bruckenstein, Quantitative Chemical Analysis, p. 666, Macmillan Co., London, England, 1969.

Synthesis of Lithium Tetraphenylborate⁷⁵ (100-II)



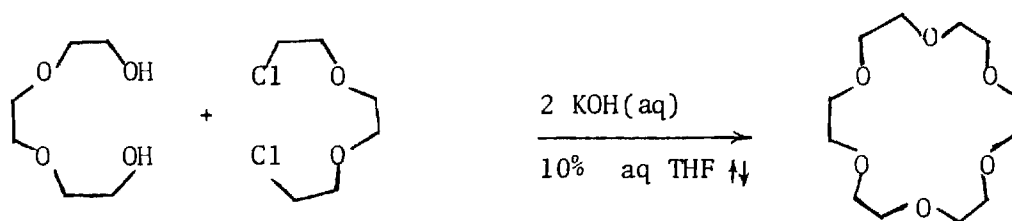
In a 500-ml 3-neck flask equipped with Teflon sleeved stirrer and Teflon blade under nitrogen in a Dry Box was added 200 ml of anhyd ether followed by 25.18 g (0.104 mole) of solid triphenylboron (mp 144.0°-149.0°) and a 50 ml ether wash of the triphenylboron ampoule. The solution was cooled to 0° and 58 ml (0.133 equivalents) of commercial phenyllithium (2.30 M in 70:30 benzene:ether) was added dropwise over 1.25 hr. The resulting slightly pink reaction mixture (excess phenyllithium) was quenched with 10 ml of wet ether followed by 10 ml of water.* The reaction mixture was allowed to stand overnight. The ether was removed and cyclohexane was added to the solid brown residue. The solid was broken up and dissolved in hot cyclohexane. The solution was cooled and filtered. The resulting brown powdery solid was dried in a desicator under vacuum for 24 hr to give 36.91 g (mp 140.0°-150.0°, dec) crude lithium tetraphenylborate. The crude product was dissolved in 200 ml ether and filtered through a

75. (a) M. Wittig, G. Keicher, A. Ruckert, and P. Raff, Justus Liebigs Ann. Chem., **563**, 110 (1948); (b) W. Gerrard, Organic Chemistry of Boron, Academic Press, New York, NY, 1961.

*In my opinion, a better yield and easier workup may have been accomplished by removing the excess phenyllithium by washing the crude reaction product with benzene, filtering, and then removing the residual ether and benzene under reduced pressure rather than by addition of water, etc. since lithium tetraphenylborate is insoluble in benzene (ref. 75b) and crystallizes with eight ether molecules in the crystalline unit.

1-1/2" x 2-1/4" dia column containing activated charcoal. The clear, ethereal solution was heated to steam bath temp at reduced pressure for 2 hr, cooled, then the residual solvent was removed in a desiccator under vacuum for 24 hr at room temperature to give 23.18 g (68.33% yield based on triphenylboron) of a slightly tan powder of mp 135.0°-140.0°, dec (reported mp 140.0°, dec).⁷⁴

Synthesis of 18-Crown-6-ether⁷⁶ (143-II)

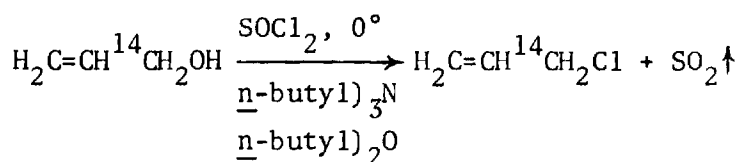


In a 3000-ml 3-neck flask equipped with mechanical stirrer, reflux condenser, and pressure-equalizing dropping funnel was added 140.0 g (2.490 g-formula wt) of potassium hydroxide pellets and 75 ml of water. The KOH was dissolved with heating and then 180.40 g (1.201 mole) of triethylene glycol was added and stirred while 500 ml THF was added. The soln began to darken after 10 min to a dark red. The solution was stirred for 1 hr and then 209.5 g (1.112 mole) of 1,2-bis(2-chloroethoxy)-ethane in 100 ml THF was added in a continuous stream over a 30 min period. After stirring for 1 hr, the reaction mixture was refluxed for 19 hr. The flask was cooled to room temperature and allowed to stir for another 9 hr. The THF was removed under reduced pressure. The residue was extracted with 750 ml CH₂Cl₂ and the CH₂Cl₂ solution was filtered and dried over anhyd MgSO₄ overnight.

76. G. W. Gokel, D. J. Cram, C. L. Liotta, H. P. Harris, and F. L. Cook, J. Org. Chem., **39**, 2445 (1974).

The extract was again filtered and concentrated at reduced pressure (steam bath temp) to give a dark oily residue which was immediately distilled through a 12"-Vigreux head at bp 115.0°/90μ-150.0°/650μ to give 78.1 g (26.7% yield based on chloride) of 18-crown-6-ether. The distilled product was transferred to an Erlenmeyer flask and 100 ml of acetonitrile added. The immediate formation of white crystals was evidence (exothermic reaction) of a 18-crown-6-ether:acetonitrile complex. The slurry was heated on a hot plate to effect dissolution and then cooled to 0° with a drying tube attached. The crystals (84.96 g) which formed were separated by rapid filtration, washed with cold acetonitrile, and dried with suction for 1-2 min. The white complex was transferred to a 250 ml flask and stoppered securely for storage. Removal of the actonitrile under vacuum with slight warming of the flask was accomplished conveniently overnight to give free, pure 18-crown-6-ether.

Synthesis of Allyl-1-¹⁴C Chloride (128-I)



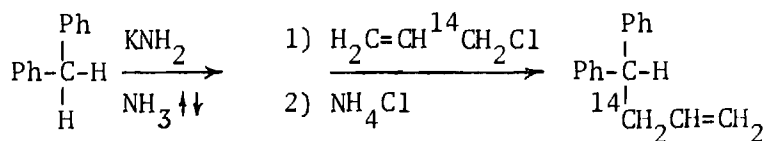
Allyl-1-¹⁴C chloride (128-I) was synthesized according to the previous method from 66.1 g (0.357 mole) of tri-n-butyl amine, 38.7 g (0.325 mole) of thionyl chloride, and 17.08 g (0.295 mole, 0.5 mC; Tracerlab) of allyl-1-¹⁴C alcohol in 38.63 g of di-n-butyl ether.⁷⁷

77. A new method of converting allylic alcohols to chlorides without rearrangement is given by E. I. Snyder, J. Org. Chem., 37, 1466 (1972).

After the crude product was distilled into the Dry Ice receivers the combined neutral distillate was distilled again at 150 mm at 25.0°-35.0° from Drierite and the pot residue was chased by addition and distillation of 4.70 g of "cold" allyl chloride to give 17.70 g of allyl-1-¹⁴C chloride* for a 58.2% absolute yield (based on starting alcohol).

A second synthesis (110-II) of allyl-1-¹⁴C chloride according to the previous method was from 66.92 g (0.361 mole) of tri-n-butyl amine, 41.37 g (0.348 mole) thionyl chloride, and 17.08 g (0.295 mole, 0.1055 mC; I.C.N.) of allyl-1-¹⁴C alcohol in 38.45 g of di-n-butyl ether. The crude product was distilled into the Dry Ice receivers, combined, and neutralized with 10% K₂CO₃. The neutral distillate was washed with water and then transferred to a flask with a 10 ml rinse of ether (should not have added) and 30 ml of acetone. The ether was slowly removed by distillation through a 6" column packed with glass helices at 1 atm and the remaining allyl chloride in acetone was stored to be used in making allyl-¹⁴C phenyl ether.*

Synthesis of 4,4-Diphenyl-1-butene-1-¹⁴C (129-I)



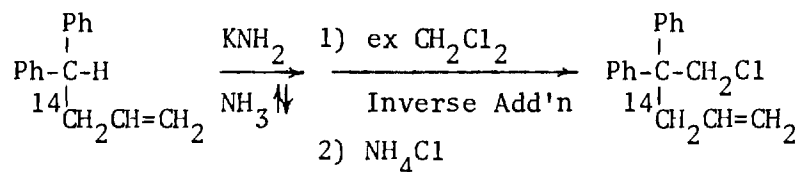
In a standard 500-ml Morton apparatus was condensed 200 ml of ammonia. Potassium amide was made from 14.91 g (0.381 g-atom) of potassium metal after which 60.0 g (0.357 mole) of diphenylmethane in

*The specific activity was not determined.

60 ml of anhyd ether was added over a 15 min period. The red soln was stirred 30 min at reflux and then 17.7 ml (0.231 mole) of allyl-1- ^{14}C chloride in 40 ml of anhyd ether was added in the manner used for the non-radioactive preparation. The reaction solution was still red after complete addition. Rather than adding more "cold" allyl chloride to quench the carbanion remaining (error!), NH_4Cl was added and the reaction product was extracted with ether. The etherate was dried and concentrated and was shown by vpc to contain 30.3% starting hydrocarbon and 69.4% desired product. The recovered organic material was then allowed to stand over Drierite in anhyd ether. Another potassium amide solution was prepared from 4.05 g (0.104 g-atom) of potassium metal after which the recovered mixture containing 14.82 g (0.088 mole) of diphenylmethane and 34.03 g (0.163 mole) of 4,4-diphenyl-1-butene-3- ^{14}C in 75 ml anhyd ether was added over a 10 min period. The red carbanion solution was stirred 5 min at -75° and then 9.39 g (0.123 mole) of neat allyl chloride was added over a 5 min period. The reaction solution changed from a deep red to a dark brown after 5 min reaction time after which the excess KNH_2 was quenched with NH_4Cl . The ether extract was concentrated to give 57.4 g crude product which was 9.8% starting hydrocarbon and 90.2% desired product (51.75 g for a 69.6% yield based on the original diphenylmethane used). Distillation of the crude product gave three fractions of which the latter amounted to 18.72 g of > 99% purity 4,4-diphenyl-1-butene-3- ^{14}C ,* bp $100.0^\circ/60\mu$, which was used to make 5-chloro-4,4-diphenyl-1-pentene-3- ^{14}C .

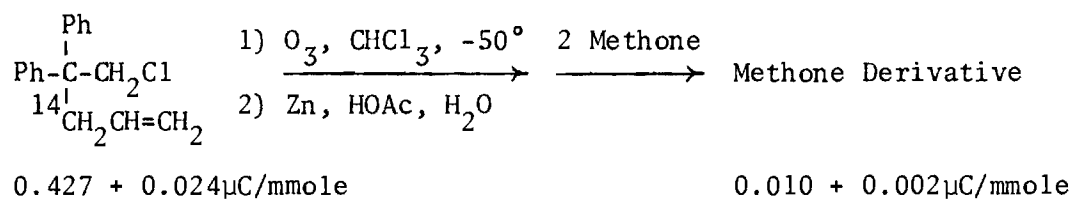
*The specific activity was not determined.

Synthesis of 5-Chloro-4,4-diphenyl-1-pentene-3-¹⁴C (132-I)



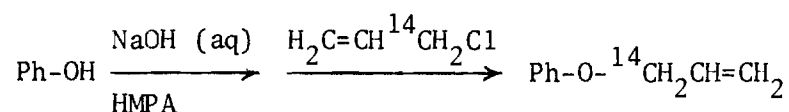
In a modified 500-ml Morton apparatus was condensed 300 ml of ammonia. Potassium amide was made from 17.5 g (0.448 g-atom) of potassium metal after which 18.72 g (0.090 mole) of 4,4-diphenyl-1-butene-3-¹⁴C in 90 ml of anhyd ether was added at -70° over a 10 min period. A reddish-black soln developed and after stirring for 40 min, the homogeneous solution was forced over, under nitrogen, into 967 g (11.40 mole) of methylene chloride (in a 2000-ml three-neck flask equipped with mechanical Teflon stirrer blade and Friedrich condenser) at -70° over a 10 min period. This inverse addition was followed by a 300 ml anhyd ether wash of the original carbanion reaction flask and the ether soln was then forced over to the second reaction flask. After the red color disappeared, a gray-brown color developed and 52.5 g (0.991 g-formula wt) of NH₄Cl was added with stirring, and then the mixture was allowed to stand as the ammonia evaporated in the hood. Workup was accomplished by adding water, removing the ether and methylene chloride at reduced pressure, filtering the product with suction, washing the solid material with methylene chloride, and separating the phases. The methylene chloride extract was dried over anhyd MgSO₄, concentrated and distilled through a 6"-Vigruex column to give 15.0 g (65.2% yield based on starting hydrocarbon) of distillate (bp 125.0°-127.0°/50μ). The pot residue was chased by 3.115 g of "cold" chloride

prepared earlier. The overall radiochemical yield* from starting allyl-1-¹⁴C alcohol was 11.29%.



The chloride was shown to have a total activity of $0.427 \pm 0.024 \mu\text{C/mmole}$ whereas the "methone" formaldehyde derivative obtained from ozonization had an activity of $0.010 \pm 0.002 \mu\text{C/mmole}$. Thus, the ¹⁴C-label was specifically incorporated (97.7%) at C-3 while only 2.3% of the label was at the C-1 terminus.

Synthesis of Allyl-¹⁴C Phenyl Ether (130-II)



To a 250-ml flask equipped with reflux condenser and magnetic stirring bar was added 28.95 g (0.308 mole) of phenol and 31.6 ml (0.294 g-formula wt) of 9.3 N NaOH with stirring to effect solution. To the sodium phenoxide soln was added 75 ml HMPA followed by addition of 15.7 g (0.205 mole) of allyl-1-¹⁴C chloride in 30 ml of acetone over a 20 min period. The reaction mixture was stirred at room

*The activity of the starting allyl-1-¹⁴C alcohol was 0.5 mC or 1.70 $\mu\text{C/mmole}$ after dilution. The activity of the final chloride was calculated (167-I) to be 56.45 μC . Thus, the radiochemical yield was 11.29% of the theoretical. This yield did not take into account the material that existed in distillation fraction 2 of the 4,4-diphenyl-1-butene-3-¹⁴C synthesis step.

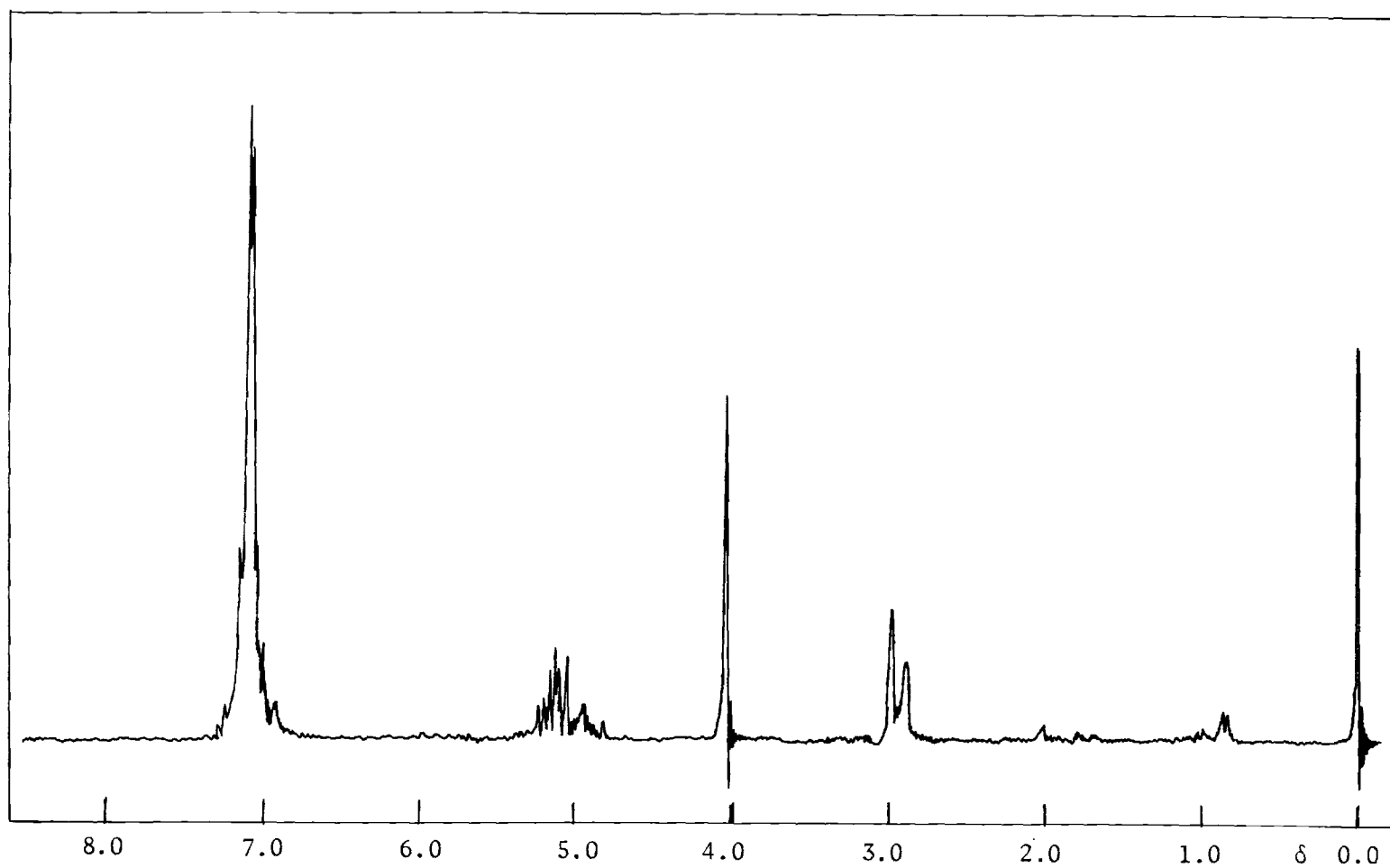
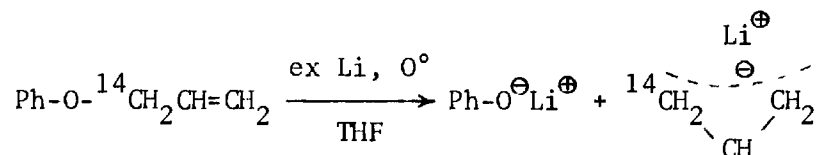


Figure 18. Nmr Spectrum (CS₂) of 5-Chloro-4,4-diphenyl-1-pentene-3-¹⁴C (132-I)

temperature for 2 hr, then refluxed for 2.5 hr, and finally cooled. The volatile components (rm temp \rightarrow 60.0°) were removed by distillation. To the remaining residue was added water and the organic material was extracted with 300 ml of ether. The ethereal extract was washed three times with 10% NaOH followed by water until the aqueous wash was neutral to pH-Hydrion paper. The ether soln was dried over anhyd MgSO_4 and distilled at bp 74.0°-75.0°/20 mm to give 10.43 g (26.45% based on starting allyl alcohol) of pure allyl- ^{14}C phenyl ether. The specific activity was, unfortunately, not measured but was estimated* to be 0.342 $\mu\text{C}/\text{mmole}$.

Preparation of Allyl- ^{14}C -lithium (134-II)



In a modified 500-ml Morton apparatus (bronze housing) was condensed 175 ml of THF. Then 12.05 g (1.736 g-atom) of freshly cut lithium wire and 0.25 ml (0.004 mole) of methyl iodide were added at room temperature. The mixture was stirred for 30 min (a slightly blue-turbid solution developed) and then cooled to 0°. Addition of 10.44 g (0.078 mole) of allyl- ^{14}C phenyl ether in 15 ml of THF was completed

*The specific activity of the starting allyl- ^{14}C alcohol was ca. 0.342 $\mu\text{C}/\text{mmole}$ (based on reported analysis by the supplier, ICN) and therefore the activity of the final allyl- ^{14}C phenyl ether was expected to be 0.342 $\mu\text{C}/\text{mmole}$ since no dilution with "cold" allyl chloride or allyl phenyl ether occurred. However, subsequent analysis of the *p*-phenylphenacyl ester of butyric acid derived from the cleavage of allyl- ^{14}C phenyl ether indicated an activity of 0.295 $\mu\text{C}/\text{mmole}$.

over a 15 min period. After one half of the allyl phenyl ether had been added, the solution began to turn yellow and had a trace of red upon completion of addition. Stirring at 0° was continued and after 1 hr, a double Gilman titration revealed 0.061 equivalents (ca. 0.307 mmoles/ml soln) of allyllithium for a 79% minimum yield.

A 25-ml aliquot (7.675 mmoles) of the allyl-¹⁴C-lithium soln was carbonated. The residue was made acidic by addition of 1 N HCl and the ether and THF was distilled through a 6"-Vigreux column. The aqueous solution was extracted with ether to remove neutral material and the ethereal extracts were combined, washed with 10% NaOH and then with water until neutral to pH-Hydrion. HCl was added to the combined aqueous layers but no milky suspension developed (only slight turbidity). This aqueous acid layer was extracted with ether to remove phenol and free acid. The ether was removed by distillation through a 6"-Claisen head (packed with glass helices) and the residual vinylacetic acid was catalytically (0.1445 g of 5% Pt on charcoal) reduced in a Parr hydrogenation apparatus in 95% ethanol at room temperature for 25 hr. The pressure drop corresponded to an uptake of 0.0088 mole of hydrogen which was equal to the maximum amount of calculated vinylacetic acid present initially. To prepare the p-phenylphenacyl ester of n-butyric⁷⁸

78. (a) p-Phenylphenacyl bromide, mp 126.0°; p-phenylphenacyl ester of n-butyric acid, mp 97.0° or 82.0°. S. P. Mulliken and E. H. Huntress, The Identification of Organic Compounds, Cambridge, MA, Facsimile Reproduction Co., 1937, p. 60; (b) the characteristic peak at δ 5.15 (s, -COCH₂-O-COH) for the derivative was not very significant. The methylene absorption of the bromide was predicted at δ 4.43 (s, -COCH₂Br) but was not as intense as was expected. A. J. Gordon and R. A. Ford, The Chemists Companion: A Handbook of Practical Data, Techniques, and References, Wiley-Interscience, John Wiley & Sons, New York, NY, 1972, p. 257.

acid, the ethanolic soln was filtered and the n-butyric acid was titrated until the soln was slightly basic. The titration indicated 0.0057 equivalents of acid was present. Thus 1.65 g (0.006 mole) of p-phenylphenacyl bromide was added to the ethanolic soln and refluxed for 1.5 hr. The hot soln was filtered and the filtrate cooled overnight as crystals formed. Addition of 10 ml of water to the filtrate caused cloudiness and the crystals which formed were collected with suction and washed with 95% ethanol/water (3:1 v/v) and then water. The brownish-cream colored crystals (1.41 g) were recrystallized from hot 95% ethanol to give 0.39 g of light beige colored crystals of unreacted p-phenylphenacyl bromide, mp 123.5°-124.5°. The solid was combined with the mother liquor, reduced in volume to a paste, made slightly basic, and treated again with 0.64 g (0.002 mole) of p-phenylphenacyl bromide. The reaction mixture was refluxed for 12 hr and the crystals were collected and recrystallized to give 0.277 g of amorphous crystals of mp 70.0°-90.0°. Another recrystallization from 95% ethanol/water with cooling gave 0.004 g of off-white beige crystals of mp 97.0°-100.0°^{78a} which underwent a phase change in the mp capillary at 68.0°-72.0°. Unfortunately, it was shown the beige crystals were not the pure p-phenylphenacyl ester of n-butyl acid but rather a mixture of the ester and starting bromide. The nmr^{78b} suggested only a very minor amount of the desired derivative was present. Analysis of the mixture by vpc indicated six components were present. The desired ester derivative comprised only 18.5% of the total peak area. The specific activity of the mixture was 0.055 ± 0.001 $\mu\text{C}/\text{mmole}$. Based on this result, the activity of the pure ester was calculated to be ca.

0.295 $\mu\text{C}/\text{mmole}$.

Organometallic Reactions

Initial Reaction (34-I) of 5-Chloro-4,4-diphenyl-1-pentene with Lithium Metal at -70°

In a standard 500-ml Morton apparatus was condensed 250 ml THF after which 0.55 g (0.079 g-atom) of freshly cut lithium wire was added. The flask was cooled to -10° , then 4.24 g (0.016 mole) of 5-chloro-4,4-diphenyl-1-pentene ("chloride") in 10 ml of THF was added over a 15 min period. After 1 hr of stirring, 0.68 g (0.005 mole) of methyl iodide was added and in 20 min a red surface could be seen on the lithium metal. The soln became orange and the flask was cooled to -75° as quickly as possible. Approximately 100 ml of solution was forced onto excess crushed Dry Ice 15 min after the reaction mixture became orange and had been cooled to -75° (carbonation I). The remainder of the reaction mixture was allowed to warm to ca. 0° for 3.25 hr and was then carbonated (carbonation II). Unfortunately, water was added prematurely to the first carbonation mixture and only neutral material was obtained. The neutral material consisted of 2.7% of 4,4-diphenyl-1-butene (4.5 min),* 26.2% of 4,4-diphenyl-1-pentene (5.9 min), and 71.1% of unreacted chloride (11.3 min), according to peak area analysis by vpc (Column A).**

Water and HCl were added to the carbonation II mixture and the THF was removed by reduced pressure. The residue was treated with 10%

*Absolute vpc retention time.

**The composition and working conditions of vpc columns used for analysis throughout this text are given in Table 2.

NaOH until basic to litmus and then the neutral material was extracted with ether. The basic aqueous layer was acidified with HCl and the free acidic material was extracted with ether to give 2.81 g (64.1%) of crude acid. Crystallization of the acid from 95% ethanol/water gave crystals which had a pre-melt at ca. 127.0° while the bulk had mp 133.0°-134.0°.* Vpc analysis (Column B) of the crude acid methyl esters showed only two peaks. The major peak (95%) was the acid corresponding to allyl migration, 2,2-diphenyl-5-hexenoic acid (18.2 min) and the minor acid (5%) corresponded to phenyl migration acid, 3 (20.0 min). The residual solution remaining in the reaction flask after the final carbonation was protonated to give neutral materials corresponding to 1.5% of 4,4-diphenyl-1-butene (4.3 min), 36.6% of 4,4-diphenyl-1-pentene, 1-RH (5.7 min) corresponding to unrearranged hydrocarbon, 57.1% of 5,5-diphenyl-1-pentene, 2-RH (6.3 min), corresponding to allyl migration hydrocarbon, and 4.9% of unreacted chloride (11.0 min), according to vpc (Column A).

Reaction (42-I) of 5-Chloro-4,4-diphenyl-1-pentene with Lithium Metal at -70°

In a standard 500-ml Morton apparatus was condensed 250 ml THF after which 1.27 g (0.184 g-atom) of freshly cut lithium wire and 1.14 g (0.008 mole) of methyl iodide were added. The flask was cooled to -10° and 5-10% of 10.71 g (0.042 mole) of chloride in 70 ml of anhyd THF was added. Stirring was continued for 1 hr as the flask was allowed to approach 0°. Immediately upon development of a pink color, the flask was cooled to -70°. The color momentarily disappeared but reappeared in 3-5 min at which time the remainder of the chloride was

*2,2-Diphenyl-5-hexenoic acid, mp 138.0°-139.0°.

added over a 10 min period. After the soln had been stirred 3 hr, a 125-ml aliquot was carbonated (I) and a 2-ml aliquot was protonated with water. The flask was then warmed to 0° and 2-ml aliquots were protonated with water after 1.5 hr and 3.5 hr at 0°. The vpc analysis of the protonated aliquots revealed that rearrangement had occurred (appearance of a second peak) and was apparently complete after 1.5 hr at 0°. Thus, after 4.0 hr at 0°, the remainder of the solution was forced onto excess crushed Dry Ice (carbonation II) and allowed to stand overnight. The THF was removed at reduced pressure and the reaction mixture was made alkaline with 10% NaOH. The neutral material was extracted from the aqueous mixture, then HCl was added and the free acids were extracted with ether. The ethereal extract was dried over anhyd MgSO₄ and concentrated. The I-neutral material (Column A) contained < 1% of 4,4-diphenyl-1-butene (2.4 min), 40.8% of 4,4-diphenyl-1-pentene, 1-RH (6.3 min) and 56.5% of the chloride (15.7 min), as well as two trace components (9.0 and 11.0 min) for a maximum of 2.7%. The II-neutral material contained 72.2% of 4,4-diphenyl-1-pentene, 1-RH (6.2 min), 12.8% of 5,5-diphenyl-1-pentene, 2-RH (6.8 min), 11.2% of an unknown (14.4 min) as well as traces (< 1%) of 4,4-diphenyl-1-butene (2.3 min), and two unknowns (4.6 and 8.8 min) according to vpc (Column A).

Vpc analysis (Column A) of the methyl esters of the I-acidic material showed 14.8% of 2,2-diphenyl-5-hexenoic acid, 2 (5.3 min), 72.9% of 3,3-diphenyl-5-hexenoic acid, 1 (6.1 min), and 11.8% of an unknown acid (9.4 min). The II-acidic material (Column A) contained 3.4% of diphenylacetic acid (14.6 min), 7.4% of 2,2-diphenyl-4-pentenoic acid (25.6 min), 85.5% of 2,2-diphenyl-5-hexenoic acid, 2 (32.2 min),

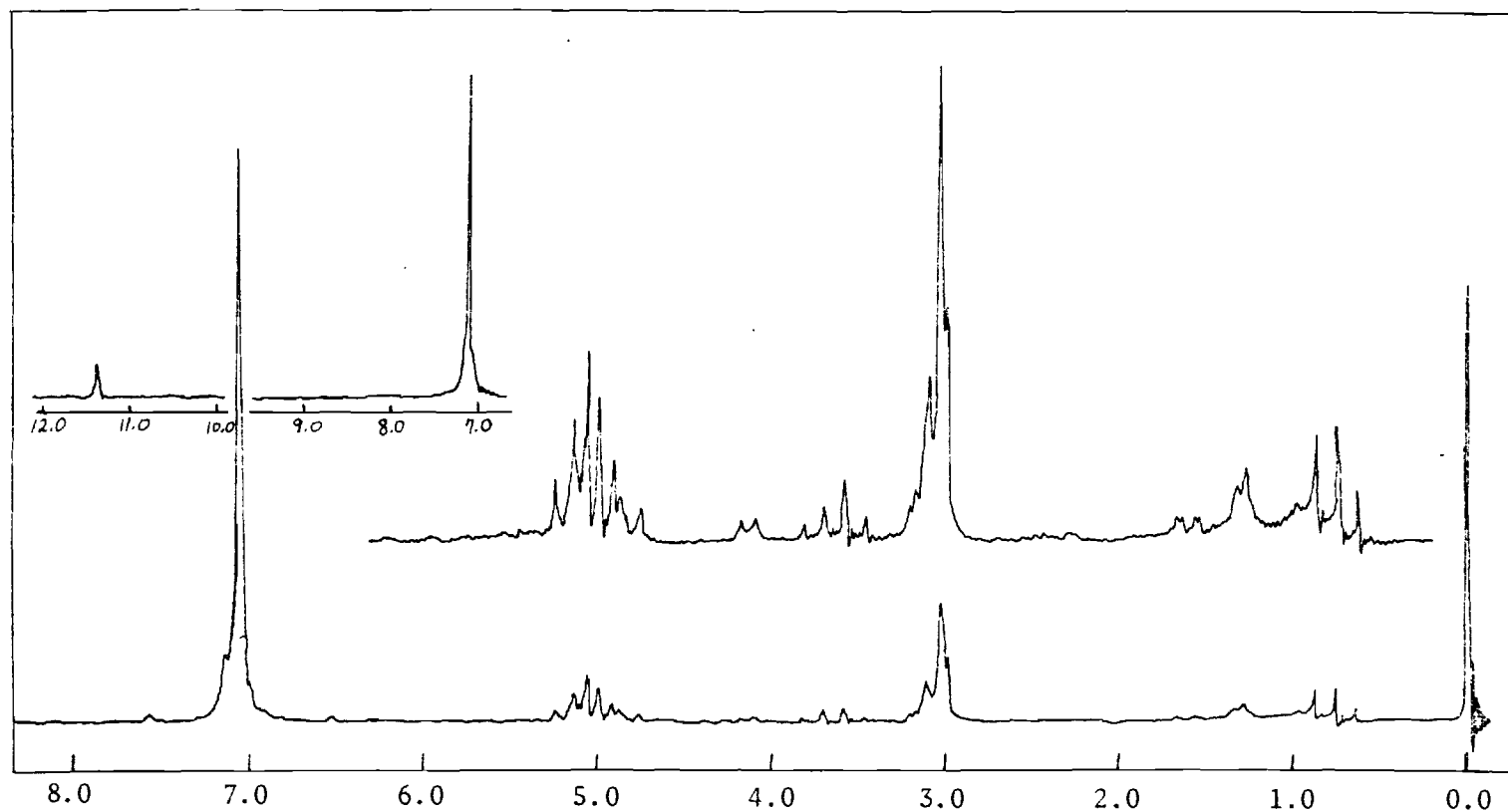


Figure 19. Nmr Spectrum (CS_2) of Unpurified I-Acid (42-I)

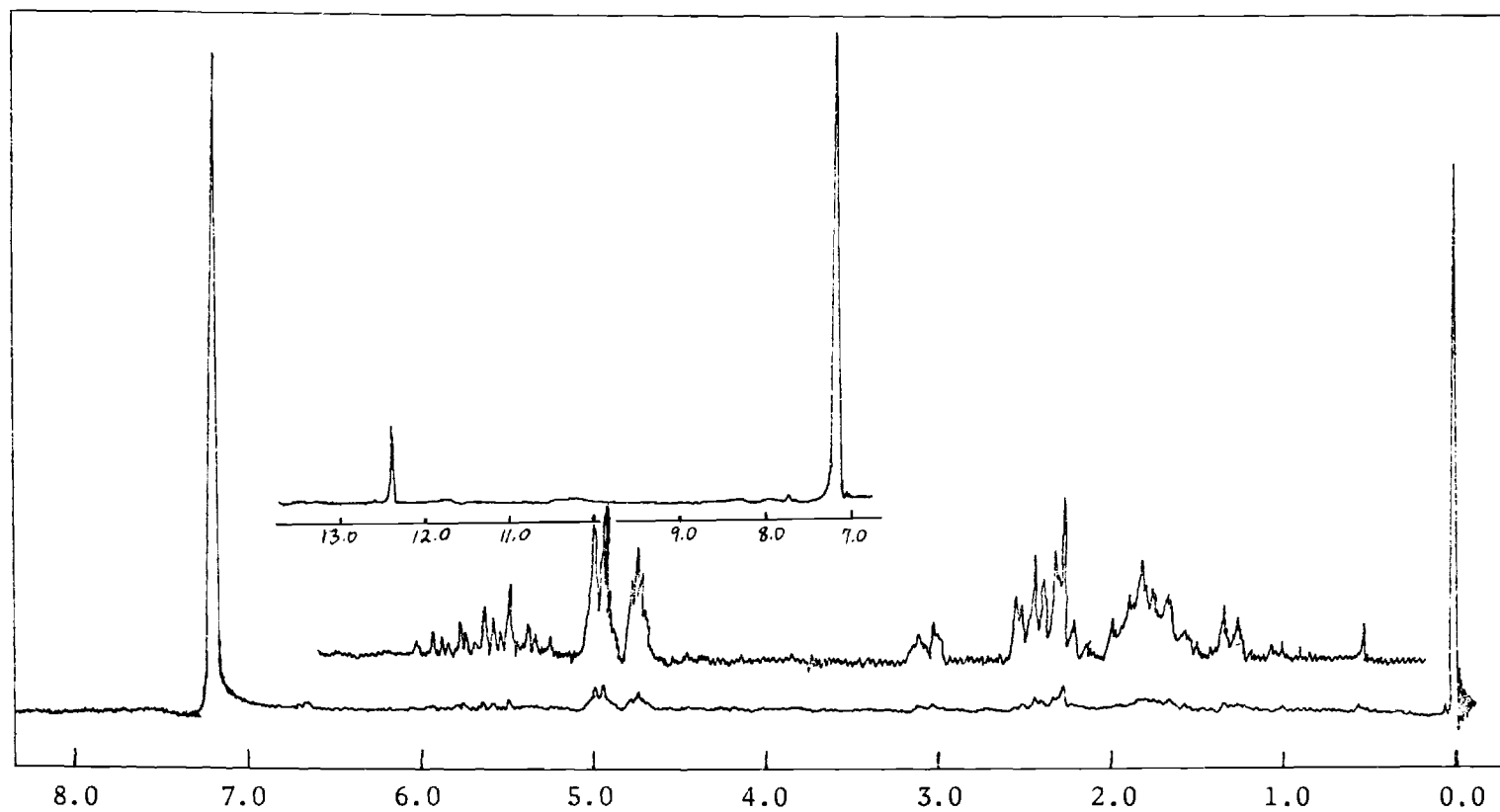


Figure 20. Nmr Spectrum (CS_2) of the II-Acid (mp 130.0° - 131.0°) (42-I)

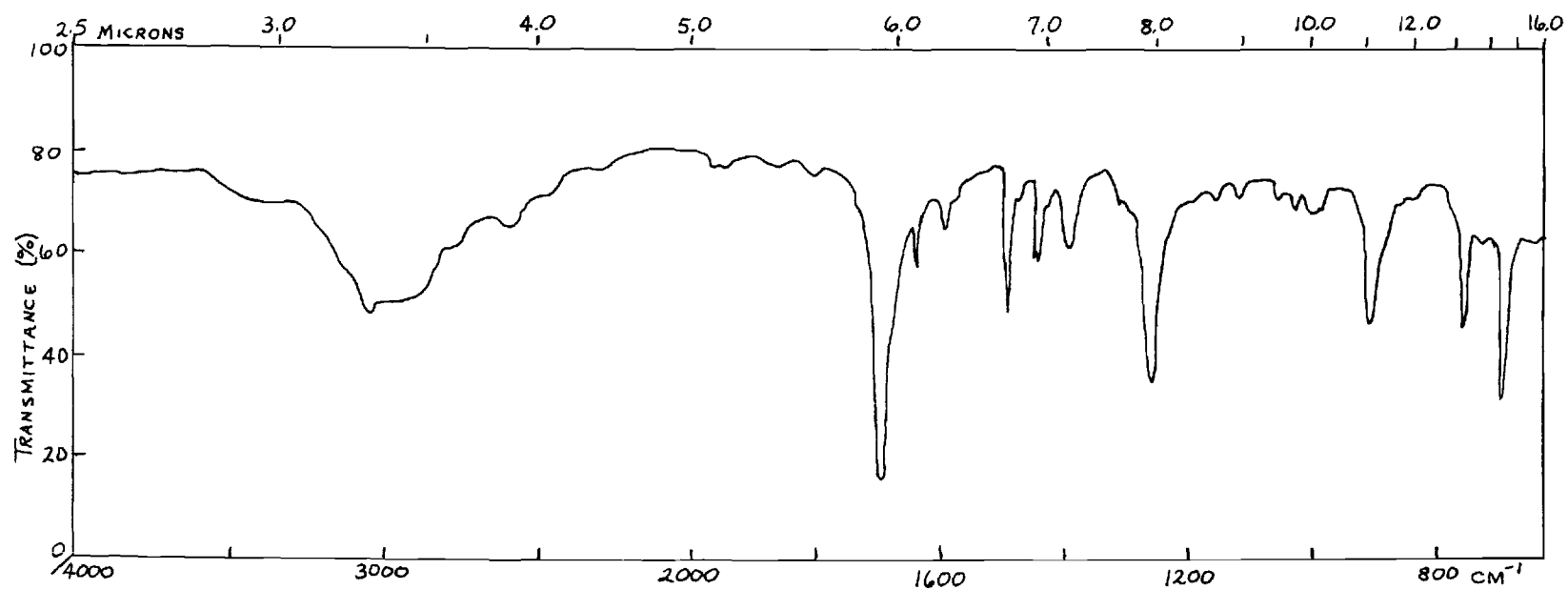


Figure 21. Infra-red Spectrum (KBr pellet) of the II-Acid (mp 130.0°-131.0°) (42-I)

3.7% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (37.8 min), and a trace of an unknown acid (55.0 min). The nmr spectrum of the crude I-acid from this reaction was consistent with the fact that the major acid component was identical to that of authentic 3,3-diphenyl-5-hexenoic acid, 1.

Acid II was purified by treating the crude acid with charcoal, filtering, and effecting crystallization from 95% ethanol-water with pentane wash to give crystals of mp 130.0°-131.0°. The melting point of the isolated acid agreed closely with that of the II-acid crystals (mp 133.0°-134.0°) of reaction 34-I and an admixture with the II-acid obtained from reaction 34-I had no depression in melting point (130.0°-132.0°). The nmr spectrum of the purified II-acid (mp 130.0°-131.0°) was identical with that of authentic 2,2-diphenyl-5-hexenoic acid, 2. The two acids showed no mixture mp depression and the infra-red spectrum matched that of authentic 2,2-diphenyl-5-hexenoic acid.*

Reaction (49-I) of 5-Chloro-4,4-diphenyl-1-pentene with Magnesium at 25°

In a standard 500-ml Morton apparatus was added 200 ml anhyd ether and 8.90 g (0.366 g-atom) of magnesium turnings. To the flask was then added 5% of 12.97 g (0.051 mole) of 5-chloro-4,4-diphenyl-1-pentene and 2.28 g (0.016 mole) of methyl iodide in 40 ml of anhyd ether. The flask was refluxed for 15 min and then cooled to room temperature when the solution became turbid. The remainder of the chloride soln was then added over a 30 min period to give a turbid

*Note: The infra-red spectrum did not match that of authentic 3,3-diphenyl-5-hexenoic acid, 1, or 2-benzyl-2-phenyl-4-pentenoic acid, 3, but was identical with that of authentic 2,2-diphenyl-5-hexenoic acid, 2.

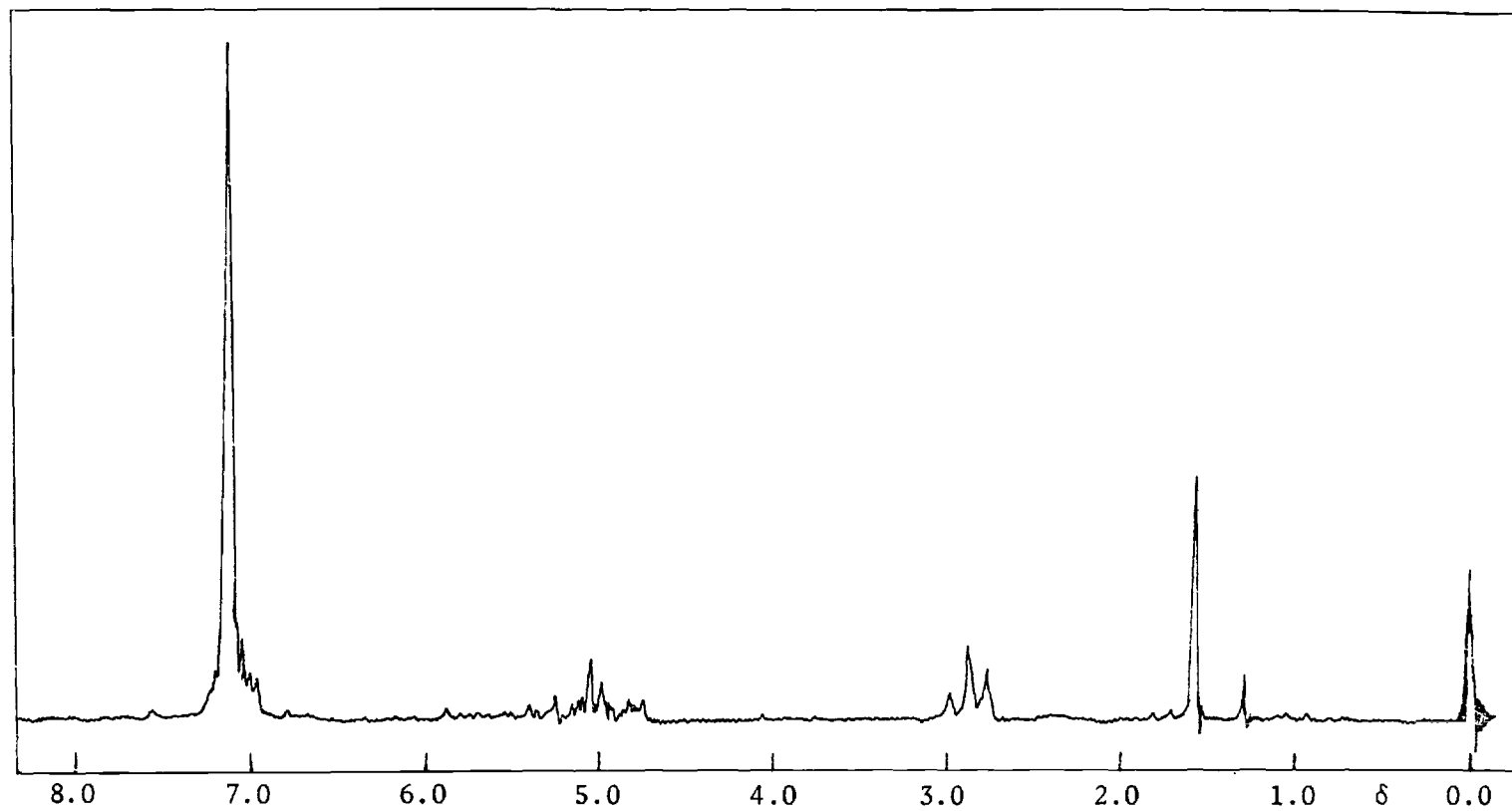


Figure 22. Nmr Spectrum (CCl_4) of Hydrocarbon (bp $74.0^\circ\text{-}84.0^\circ/100\mu$) from the Grignard Reaction 49-I

greenish-brown solution. After a reaction time of 6 hr, an aliquot was protonated and vpc analysis indicated only 5% of the chloride remained. A double Gilman titration⁷⁹ indicated a Grignard reagent yield of 80%. At this time, 150 ml of solution was forced onto excess crushed Dry Ice and allowed to stand overnight while the residual solution (50 ml) in the flask was protonated with water. The crude acid mixture (ca. 4 g) was not purified since it could not be purified by recrystallization. However, the volatile neutral material (ca. 6 g) obtained from the protonated material contained 93.6% of 4,4-diphenyl-1-pentene, 1-RH (5.8 min) and 6.4% of 4,4-diphenyl-1-butene (4.8 min) according to vpc analysis (Column A). The hydrocarbon was further purified (ca. 95% pure) by distillation in a Hickman still at bp 74.0°-84.0°/100μ and was identified* as 4,4-diphenyl-1-pentene, 1-RH and apparently was formed by solvent protonation. The nmr spectrum (CCl₄) had absorption at δ 1.58 (2.7 H, s, -CH₃ at C-5), 2.82 (2.0 H, d, J = 6.0 Hz, -CH₂-on C-3; an impurity absorbs as a doublet centered at δ 2.92 and as a singlet at δ 1.30), 4.73-5.90 (3.2 H, complex m, -CH=CH₂), 7.10 (12.7 H, m, Ph₂-), which was consistent with authentic 4,4-diphenyl-1-pentene.**

79. Allyl chloride or benzyl chloride was used: H. Gilman and A. H. Haubein, J. Amer. Chem. Soc., **66**, 1515 (1944); H. Gilman and F. K. Cartledge, J. Organometal. Chem. (Amsterdam), **2**, 447 (1964).

*The infra-red spectrum of the Hickman distillate (see Appendix) was identical to that of independently synthesized 4,4-diphenyl-1-pentene.

**The impurity (ca. 20%) was believed to be 4,4-diphenyl-2-pentene based on the fact there is a singlet at δ 1.3, a doublet centered at δ 1.92, and a somewhat higher (ca. 20%) than expected proton count for the vinyl and aromatic region.

Anal. (Galbraith) Calcd for $C_{17}H_{18}$: C, 91.84, H, 8.16. Found: C, 91.67, 91.75; H, 8.30, 8.22.

Reaction (61-I) of 5-Chloro-4,4-diphenyl-1-pentene with Magnesium at 35°

To a standard 500-ml 3-neck flask under nitrogen atmosphere equipped with magnetic stirring bar and water condenser, was added 3.42 g (0.141 g-atom) of magnesium metal and 10 drops of methyl iodide with sufficient anhyd ether to cover the metal. After 30 min at reflux 14.86 g (0.058 mole) of 5-chloro-4,4-diphenyl-1-pentene in 15 ml anhyd ether was added over a 15 min period. The ether soln (ca. 100 ml) was refluxed for 6 hr after which it was determined that reaction was complete (i.e., the chloride had reacted completely according to vpc). The silvery-green Grignard soln was cooled to room temperature and Dry Ice was added to the flask, followed by water 10 min later. HCl was finally added to dissolve the excess magnesium metal and the reaction flask was allowed to stand overnight. Extraction of the acidified aqueous solution with ether gave 13.34 g crude organic material of which 10.19 g was neutral material and 3.15 g (20.4% yield) was crude acid. The acid was separated by extraction of the ether phase with aqueous KOH, separating the aqueous layer, and acidifying the latter with HCl and extracting the free acid with ether. The ethereal solution was concentrated but unfortunately the relative and absolute yield of 3,3-diphenyl-5-hexenoic acid was shown to be quite low, ca. 2%. Analysis of the methyl ester mixture by vpc (Column F) gave 2.0% (0.526)* of an unknown acid, no 2,2-diphenyl-4-pentenoic acid (internal standard,

*Vpc relative retention time.

1.000), 11.5% (1.235) of 2,2-diphenyl-4-hexenoic acid,* 2', 57.0% (1.490) of 2-benzyl-2-phenyl-4-pentenoic acid, 3; 11.5% (1.544) of 3,3-diphenyl-4-hexenoic acid,* 1', and two unknown acids of 7.2% (1.705) and 10.5% (1.866) area percent respectively. The nmr spectrum** of the methyl ester mixture when compared to the nmr spectrum (Figures 5, 9, and 14) of the independently synthesized acids (i.e., unrearranged acid, 1, allyl migration acid, 2, and phenyl migration acid, 3) clearly shows the characteristic phenyl migration product absorption to be the major component with the remainder of the compounds in minor proportions. The mass spectrum (Varian) of the free acid mixture gave ions (relative intensity) at 266 (0.3, M⁺), 264 (1), 234 (1), 221 (15), 220 (66), 219 (17), 206 (19), 205 (100), 204 (26), 203 (20), 203 (15), 178 (18), 165 (16), 149 (79), 129 (56), 128 (27), 115 (18), 91 (40), 77 (15), 57 (15), 44 (40), 32 (31), 28 (58), 18 (40).

Reaction (97-I) of 5-Chloro-4,4-diphenyl-1-pentene with Magnesium in THF

In a standard 500-ml Morton apparatus was added 2.00 g (0.082 g-atom) of magnesium, 1.14 g (0.008 mole) of methyl iodide, and 25 ml of THF to cover the metal. After standing 10 min, the THF became yellowish-orange and then an additional 225 ml of THF was added after which 10.63 g (0.042 mole) of chloride with 0.57 g (0.004 mole) of methyl iodide in 10 ml THF was added over a period of 10 min at room temperature. Aliquots were taken at various times and protonated with

*Identification is based on deviation of relative retention time and of nmr spectral evidence for double bond migration, not authentic compounds.

**Courtesy of Dean Quest (nmr spectrum of the free acid mixture).

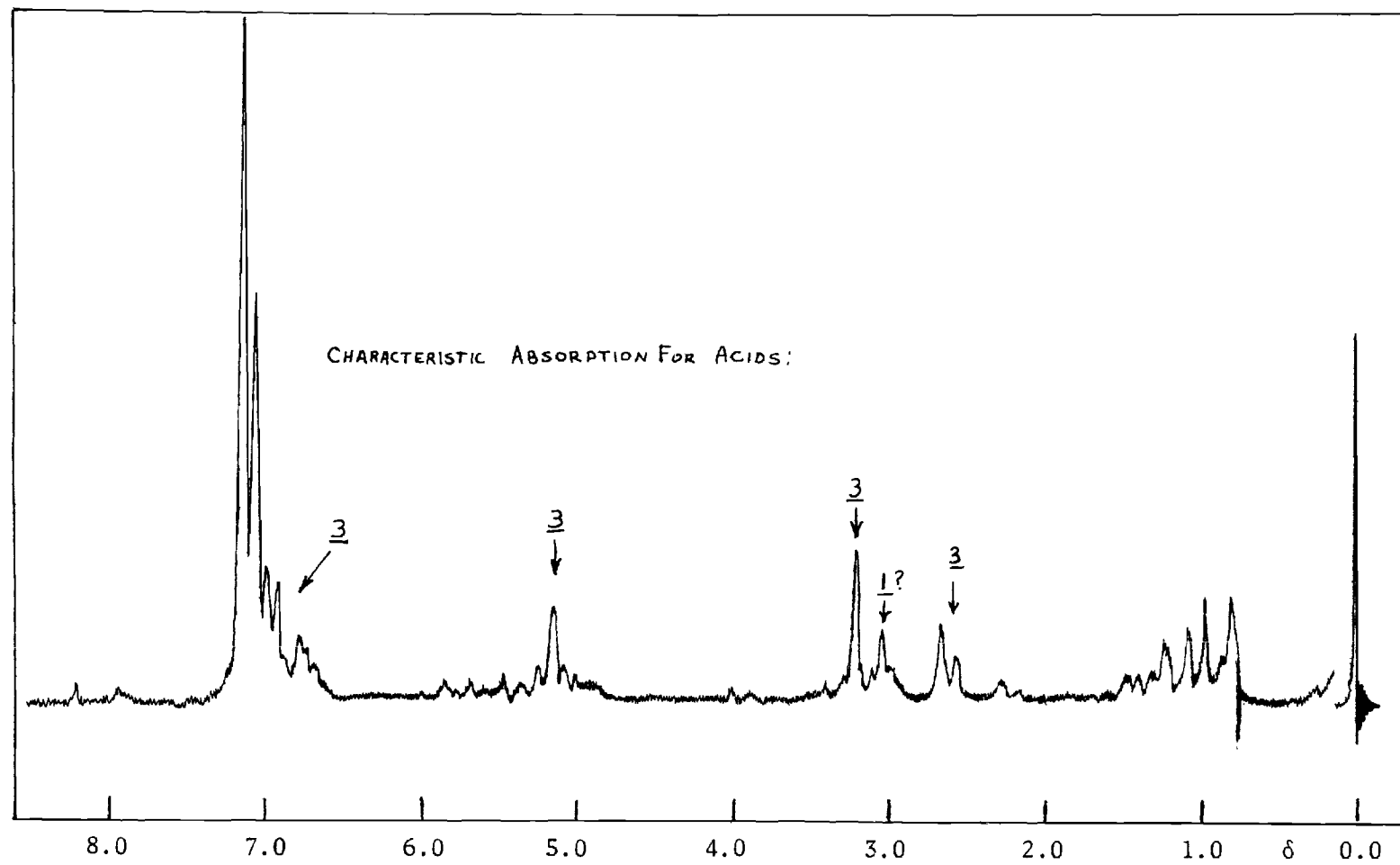


Figure 23. Nmr Spectrum (CS_2) of Crude Acid Mixture of Grignard Reaction 61-I

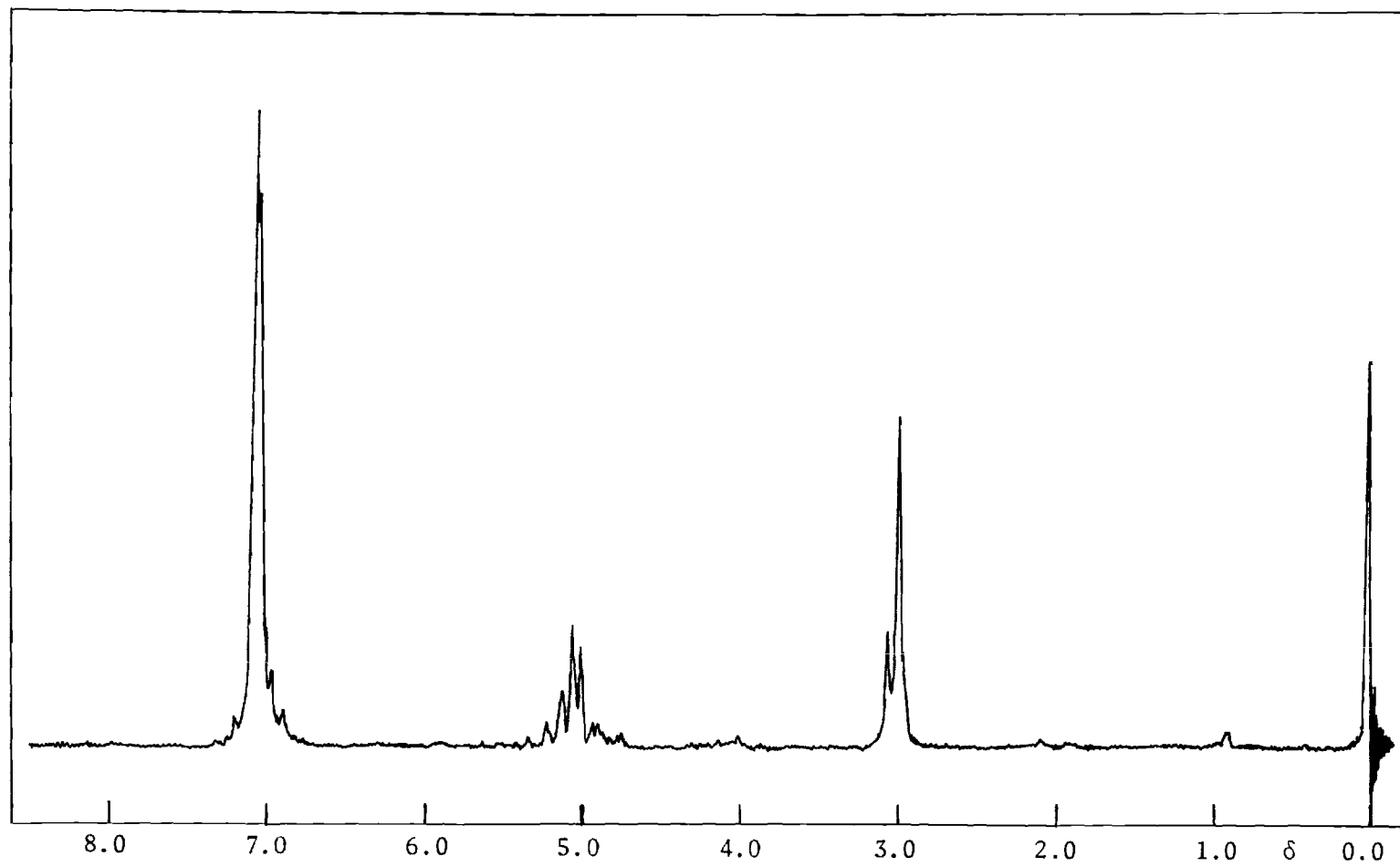


Figure 24. Nmr Spectrum (CS_2) of the Acid (mp 105.0° - 106.0°) from Grignard Reaction 97-I

water. The reaction of the chloride was ca. 50% complete after 4.75 hr at room temperature and then reflux was begun. After 120 hr, the solution was cooled to room temperature and forced onto excess crushed Dry Ice. After usual workup, 6.37 g of neutral material and 4.79 g (43.2% yield) of acidic material was recovered. Vpc analysis (Column A) showed the neutral material contained 70.1% of 4,4-diphenyl-1-pentene, 1-RH (3.9 min), 2.3% of an unknown (5.0 min), 17.9% of an unknown, chloride isomer (?), (7.1 min), 4.8% of chloride (10.4 min), and four other minor components (1.5, 2.1, 3.2, and 1.0 min) totaling 7.2%. The acidic material contained 2.4% diphenylacetic acid (3.0 min), 0.4% of 2,2-diphenyl-4-pentenoic acid (5.2 min), 93.1% of 3,3-diphenyl-5-hexenoic acid, 1 (8.1 min), and 4.1% of an unknown (9.5 min) according to vpc (Column A). An nmr spectrum of the acid (98+ area % purity) which was recrystallized from pentane (mp 105.0°-106.0°) was identical to that corresponding to authentic 3,3-diphenyl-5-hexenoic acid while an admixture melting point with authentic 3,3-diphenyl-5-hexenoic acid showed no mp depression.

Reaction (99-I) of 5-Chloro-4,4-diphenyl-1-pentene with Lithium

In a standard 500-ml Morton apparatus was condensed 250 ml of THF and 1.18 g (0.171 g-atom) of lithium wire was added. The flask was cooled to -75° after which 11.32 g (0.044 mole) of chloride with 2.28 g (0.016 mole) of methyl iodide in 15 ml of anhyd THF was added over a 15 min period. The flask was warmed to -35° to initiate the chloride reaction and in 35 min a red surface could be detected on the lithium metal; then, the reaction was cooled over a period of 30 min to -75° and allowed to react further. The solution became black-red

as the reaction developed and 1-ml aliquots were withdrawn and protonated at various intervals of time. After a total reaction time of 16 hr at -75° , the initially formed carbanion, 2,2-diphenyl-4-pentenyl-lithium was allowed to rearrange as the flask was warmed to $0^{\circ} \pm 5^{\circ}$. After 4 hr at ca. 5° , the black-red solution was forced onto excess crushed Dry Ice. Workup gave 5.89 g of neutral material and 4.22 g (36.01% yield) of acidic material. The neutral material according to vpc (Column A) was composed of 1.4% of 4,4-diphenyl-1-butene (2.9 min), 64.5% of 4,4-diphenyl-1-pentene, 1-RH (3.75 min), 22.1% of 5,5-diphenyl-1-pentene, 2-RH (4.2 min), 7.0% of an unknown compound (4.6 min) and 5.0% of an unknown compound (9.9 min). The acidic material contained only a trace of two impurities $< 2\%$ (5.8 and 8.0 min) with the major acid (98%) being the product of allyl migration, 2,2-diphenyl-5-hexenoic acid, 2 (7.6 min) according to vpc analysis (Column A).

Further analysis* of the hydrocarbons obtained on protonation of the aliquots suggested that the migration of the allyl group had a pseudo-first-order rate constant of 0.022 min^{-1} and 0.048 min^{-1} at an average temperature of -35° and -10° respectively.⁸⁰ The energy of activation as determined from the first-order kinetic plot and the

*The kinetic and thermodynamic parameters suggested by this analysis are extremely crude and may be quite inaccurate. A more accurate determination of ΔE_a , ΔH^{\ddagger} , and ΔS^{\ddagger} will follow in the discussion.

80. Calculated using the equation $\ln(x_0/x) = k\Delta t$: x_0 equals the maximum relative percent of rearranged hydrocarbon observed and x equals the relative percent rearranged hydrocarbon at time, t ; Δt equals the time elapsed between the corresponding values of x and x_0 while k is the unknown pseudo-rate constant of the rearrangement. J. Rose, Dynamic Physical Chemistry, John Wiley and Sons, Inc., New York, NY, 1961, p. 723.

Arrhenius equation gave a value of $\Delta E_a = 4.5$ kcal/mole. The corresponding values for ΔH^\ddagger and ΔS^\ddagger at -35° were calculated⁸¹ to be 4.0 kcal/mole and -58.0 e.u., respectively.

Reaction (118-I) of 5-Chloro-4,4-diphenyl-1-pentene with Lithium at -32°

In a standard 500-ml Morton apparatus was condensed 250 ml THF after which 1.38 g (0.200 g-atom) of lithium wire was added. The flask was cooled to -75° and then 4.71 g (0.018 mole) of chloride with 1.14 g (0.008 mole) of methyl iodide in 30 ml of anhyd THF was added over a 15 min period. Reaction was visible within 10 min and, as the reaction proceeded, 1-ml aliquots were withdrawn and protonated by water. The chloride was completely reacted after 6 hr at -75° and then the flask was warmed as rapidly as possible to $-32^\circ \pm 3^\circ$ and again 1-ml aliquots of the solution were taken over a 4 hr period and protonated by water. Analysis by vpc (Column C) of the ratio of hydrocarbons corresponding to unrearranged and allyl migration products gave a simple first-order plot for the disappearance of unrearranged organolithium compound. The rearrangement had an apparent pseudo-rate constant of $k = 0.012 \text{ min}^{-1}$ with a corresponding half-life* of $t_{1/2} = 55.5 \text{ min}$ at -32° . However, this value assumes erroneously that all the hydrocarbon was as a result of the water quench at various times. Therefore, since one should and could allow for protonation of the organolithium compound by the solvent and reaction system, it was possible to obtain a corrected half-life.

81. J. F. Bunnett, Investigation of Rates and Mechanisms of Reactions, Part I, 3rd ed., E. S. Lewis, Ed., Techniques of Chemistry, Vol. VI, Wiley-Interscience, New York, NY, 1974, Chapter VIII.

*Calculated using the equation: $t_{1/2} = (1/k) \ln 2$.

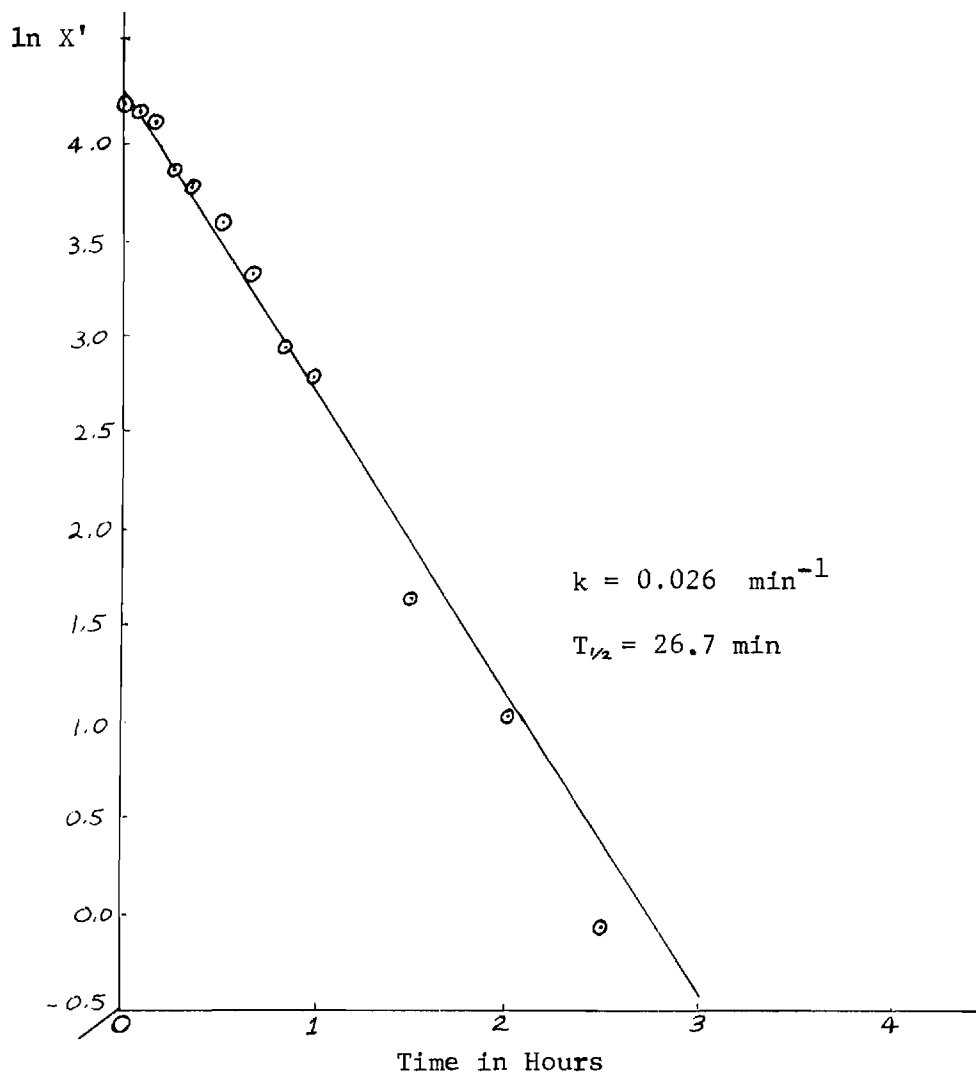
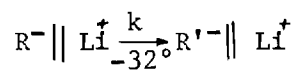
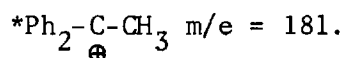


Figure 25. First-Order Plot (118-I) for the Disappearance of Organolithium Compound; X' Equals the Percent Carbanion Available for Rearrangement at Time, t

The corrected value was calculated by assuming that the organolithium compound which was protonated by the solvent, etc., was equal to the unrearranged hydrocarbon remaining (32%) ("steady state concentration") after all of the known "live carbanion" had undergone allyl migration. This "steady state concentration" was then subtracted from the total relative area percent corresponding to the unrearranged hydrocarbon to give the relative percent of "live carbanion" available for rearrangement, X'. Thus, the corrected half-life was calculated to be; $t_{1/2} = 26.7$ min.

The relative amount of "live" vs solvent protonated organolithium compound was provided by the mass spectrum of the hydrocarbons from a D₂O quench of an aliquot taken immediately prior to warming the solution. Neglecting any isotope effect, the ratio of peaks 181* and 182 for I-RH and I-RD, respectively, could be measured (based on the known RH spectrum of authentic unrearranged hydrocarbon) to calculate** that 33% of the organolithium compound had been protonated by the solvent prior to warming (in agreement with the vpc data) and thus was not available for rearrangement.

This assumption was supported by the analysis of a 25-ml aliquot that, after 4 hr at -32°, was forced onto excess crushed Dry Ice to give after workup 1.56 g of crude material*** and 0.45 g of crude acidic



**Correction for ^{13}C was taken into account in the calculation.

***The unusually high amount of neutral material vs acidic material for this aliquot when compared to the data of other aliquot samples leads one to doubt the validity of the data either through sampling technique or subsequent analysis.

material. Vpc analysis (Column D) of the neutral material from the carbonation contained 69.7% of unrearranged hydrocarbon, 1-RH (5.7 min), 20.2% of allyl migration hydrocarbon, 2-RH (6.3 min) and 10.1% of an unknown component (6.7 min). The acidic material (Column D) corresponded to 98.0% of allyl migration acid, 2 (11.0 min), and 2.0% of phenyl migration, 3 (12.0) min. The bulk of the remaining carbanion solution in the flask after warming was quenched with water to give 2.94 g of neutral material containing 30.2% of unrearranged hydrocarbon, 1-RH (6.6 min) and 69.8% of allyl migration hydrocarbon, 2-RH (7.5 min) thereby illustrating the fact that while no "live unrearranged carbanion" remained after 4 hr, there was in fact (30%) neutral material corresponding to unrearranged hydrocarbon, I-RH, as a result of solvent protonation.

Reaction (79-II) of 5-Chloro-4,4-diphenyl-1-pentene with Lithium

In a modified 500-ml Morton apparatus was condensed 250 ml of THF and 3.58 g (0.517 g-atom) of lithium wire was added, followed by 1.14 g (0.008 mole) of methyl iodide. The flask was cooled to -75° and then 0.44 g (0.005 mole) of n-butyl chloride was added and allowed to react for 30 min. Addition of 2.68 g (0.010 mole) of the chloride in 12 ml of THF was completed over a 10 min period and reaction (detected by the immediate development of a red colored solution) was complete after 3 hr. After 5.5 hr, a 15-ml aliquot was carbonated (I). A 100-ml aliquot was warmed to 0° , another 100-ml aliquot was warmed to -50° , while the remaining 20 ml of solution was warmed to -30° .

Protonation of a 1-ml aliquot of the original carbanion solution after 4 hr at -75° gave neutral material corresponding to 6.0% of

suspected 4,5-diphenyl-1-pentene, 3-RH (7.7 min), 91.3% of 4,4-diphenyl-1-pentene, 1-RH (8.4 min), and 2.7% of an unknown compound (19.4 min), according to vpc analysis (Column E).

Aliquots of the 100-ml sample of solution at 0° protonated with time at 1, 2, and 3 hr showed the rearrangement to have been completed in less than 1 hr as the neutral material was composed (Column E) of 9.9% of supposed 4,5-diphenyl-1-pentene, 3-RH (7.7 min), 14.5% of 4,4-diphenyl-1-pentene, 1-RH (8.5 min), 72.6% of 5,5-diphenyl-1-pentene, 2-RH (9.8 min), and 3.0% of an unidentified compound (19.4 min). Aliquots of the 20-ml sample of solution at -30° protonated with time at 1, 1.5, 2, 2.5, 3, and 4 hr indicated rearrangement was complete after 2 hr. The neutral material* (Column E) was composed of 10.0% of supposed 4,5-diphenyl-1-pentene, 3-RH (4.4 min), 35.6% of 4,4-diphenyl-1-pentene, 1-RH (4.8 min) and 47.6% of 5,5-diphenyl-1-pentene, 2-RH (5.6 min), and 6.8% of an unknown compound (11.4 min). Aliquots of the 100-ml portion of solution at -50° which were protonated with time at 1, 2, 3, 4, 6, 8, and 12 hr indicated the rearrangement was very slow at -50° since the aliquot protonated after 12 hr gave neutral material (Column E) which was composed of 6.9% (supposedly) 4,5-diphenyl-1-pentene, 3-RH (4.3 min), 63.5% of 4,4-diphenyl-1-pentene, 1-RH (4.7 min), 22.7% of 5,5-diphenyl-1-pentene, 2-RH (5.5 min), and 6.9% of an unknown compound (10.9 min).

The acidic material (Column F) from carbonation I (-75°) gave

*This aliquot was prematurely quenched by atmospheric moisture, thus the high (35.6%) percentage of unrearranged hydrocarbon, 1-RH, is an anomalously high value for a completely rearranged system.

0.25 g of acids composed of a trace (< 1%) of unknown acid (0.325),* 3.1% of 2,2-diphenyl-5-hexenoic acid, 2 (1.281), 89.3% of 3,3-diphenyl-5-hexenoic acid, 1 (1.590), and 7.6% of an unknown compound (1.963) relative to the internal standard, 2,2-diphenyl-4-pentenoic acid (1.000).

The acidic material (Column F) from carbonation II (residue of solution after 4 hr at 0°) gave 0.88 g of acids composed of 3 trace components (0.318, 0.680, and 1.170) of less than 3% total, 62.4% of 2,2-diphenyl-5-hexenoic acid, 2 (1.286), 5.0% of an unknown compound (1.360), 1.7% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.490), 7.8% of 3,3-diphenyl-5-hexenoic acid, 1 (1.576), and 6.0% of 2,2-diphenyl-heptanoic acid (1.729).

The acidic material (Column F) from carbonation III (residue of solution after 12 hr at -50°) gave 0.30 g of acids composed of 43.0% of 2,2-diphenyl-5-hexenoic acid, 2 (1.283), 1.7% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.495), 57.0% of 3,3-diphenyl-5-hexenoic acid, 1 (1.574), and less than 5% of an unknown compound (1.936).

Reaction (22-II) of 2,2-Diphenyl-4-pentenyllithium with Potassium tert-Butoxide

In a modified 500-ml Morton apparatus was condensed 250 ml of THF and then 7.37 g (1.062 g-atom) of lithium wire and 2.28 g (0.016 mole) of methyl iodide was added. The flask was cooled to -75° and 0.88 g (0.010 mole) of n-butyl chloride was added and allowed to

*The number appearing in parenthesis after the compound is the relative retention time of the compound eluted relative to the internal standard; 2,2-diphenyl-4-pentenoic acid.

react for 30 min after which 3.20 g (0.012 mole) of chloride in 10 ml anhyd THF was added over a 15 min period. Immediately on addition of the chloride, the solution developed a slight pink color which soon became red-orange. After 30 min, a 1-ml aliquot of the reaction mixture was protonated with water and analyzed by vpc. No chloride remained; only the peak corresponding to unrearranged hydrocarbon, 1-RH was formed. Forty minutes later, 125 ml of the reaction mixture was forced onto excess crushed Dry Ice (carbonation I). To the remaining solution at -75° was added 125 ml (0.371 equivalents) of freshly prepared potassium tert-butoxide in THF at -75° . The solution was stirred to mix the reagents and 1-ml aliquots were protonated immediately, after 5 min, and after 20 min on mixing (ca. 5 min total elapsed time from initial addition of alkoxide soln till the first aliquot was protonated). The bulk of the solution was then forced onto excess crushed Dry Ice (carbonation II) 30 min after the addition of the alkoxide soln. The neutral material (Column G) from Carbonation I amounted to 0.22 g and contained two unidentified components of 4.2% and 3.9%, respectively (13.9 and 14.6 min), 67.6% of 4,4-diphenyl-1-pentene, 1-RH (17.8 min), 8.4% of 5,5-diphenyl-1-pentene, 2-RH (19.8), and 14.4% of an unknown compound (29.8 min, chloride isomer?). The neutral material (Column G) from carbonation II amounted to 1.1 g composed of 6.3% of an unknown component (7.0 min), 18.01% of supposed 4,5-diphenyl-1-pentene, 3-RH (17.3 min), 52.7% of 4,4-diphenyl-1-pentene, 1-RH (18.2 min), 11.6% of 5,5-diphenyl-1-pentene, 2-RH (20.2 min), and 5.1% each of two unknown compounds (21.9 and 29.6 min).

The acidic material (Column G) from carbonation I gave 1.49 g

acid composed of 2.1% of 2,2-diphenyl-5-hexenoic acid, 2 (33.7 min) and 97.9% of 3,3-diphenyl-5-hexenoic acid, 1 (41.4 min). The mass spectrum of the carbonation I free-acid mixture was essentially the same as that of authentic 3,3-diphenyl-5-hexenoic acid with ions at 266 (M⁺, 3), 226 (30), 225 (100), 184 (17), 183 (89), 179 (17), 178 (23), 165 (33), 129 (12), 128 (10), 115 (9), 105 (32), 103 (53), 91 (21), 77 (29).

The mass spectrum of 2,2-diphenyl-5-hexenoic acid had ions at 266 (M⁺, 3), 221 (34), 213 (15), 212 (86), 211 (22), 194 (21), 180 (19), 179 (22), 178 (25), 167 (71), 166 (40), 165 (100), 152 (18), 143 (18), 133 (12), 129 (12), 128 (14), 118 (16), 117 (55), 115 (19), 105 (30), 103 (37), 91 (87), 77 (45), 55 (15), 41 (16), 39 (19). The mass spectrum of 2-benzyl-2-phenyl-4-pentenoic acid had ions at 266 (M⁺, 15) 225 (9), 181 (7), 179 (8), 178 (9), 175 (23), 131 (13), 129 (43), 128 (10), 115 (8), 107 (13), 105 (4), 103 (8), 92 (10), 91 (100), 77 (13).

The acidic material (Column G) from carbonation II amounted to 0.95 g of acid composed of 1.9% 2,2-diphenyl-4-pentenoic acid (1.000), 27.5% of 2,2-diphenyl-5-hexenoic acid, 2 (1.259), 6.7% of an unknown compound believed to be 2-benzyl-2-phenyl-3-pentenoic acid (1.320), 62.3% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.459), and 1.6% of 2,2-diphenylheptanoic acid (1.683). The mass spectrum* of the carbonation II free-acid mixture did not agree with either acid 1, 2, or

*This was the first evidence for phenyl migration. The mass spectrum of carbonation II acids did not correspond to either unrearranged acid, 1, or allyl migration, 2. Thus, the other obvious possibility (excluding double bond isomerization) was that phenyl

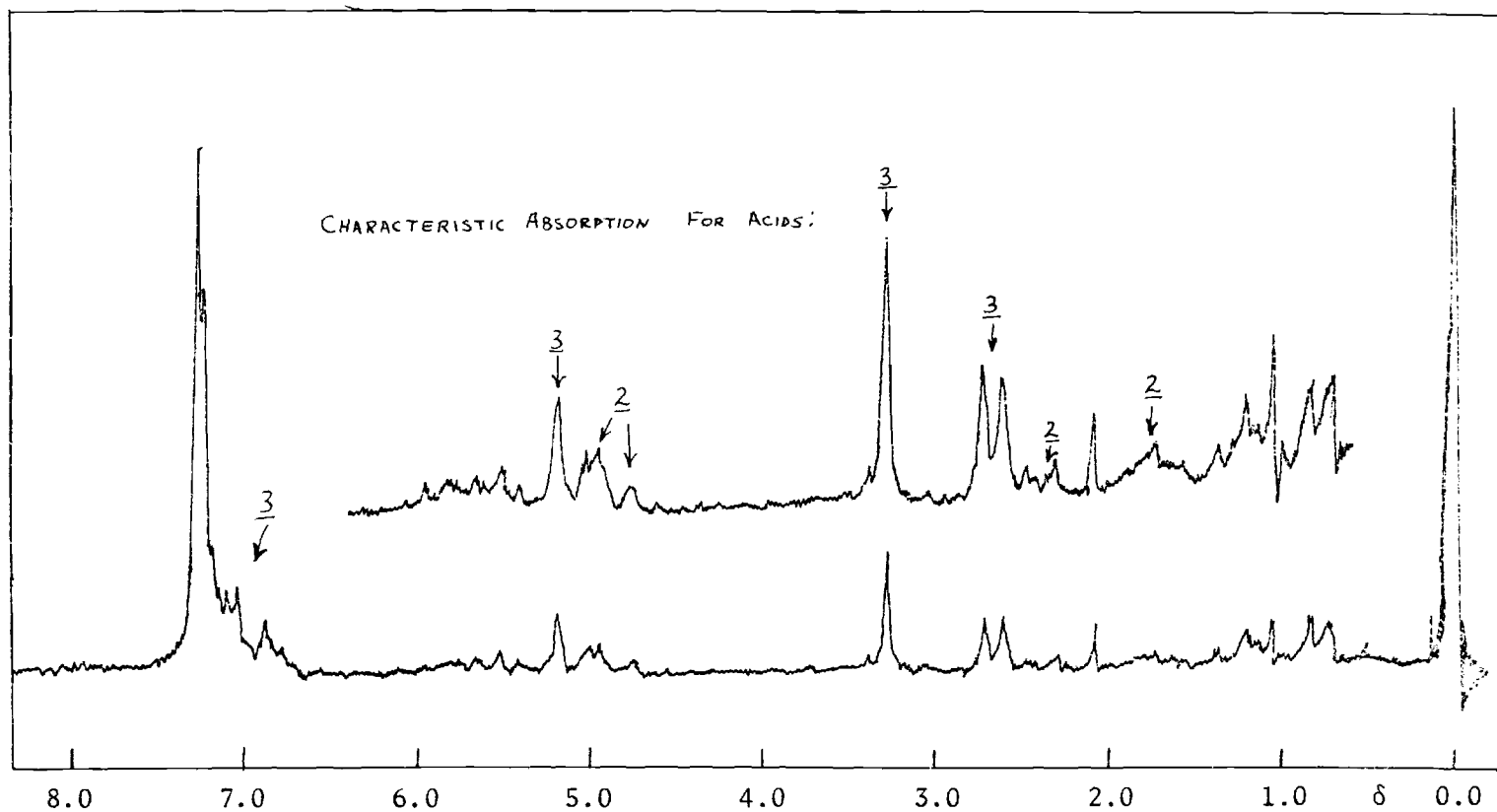


Figure 26. Nmr Spectrum (CDCl_3) of II-Acid Mixture (KO-t-butoxide added) from Reaction 22-II

3; however, the spectrum was very complex and indicated that a mixture of acids 2 and 3 (perhaps among others) was present. The spectrum had ions at 266 (M⁺, 13), 248 (9), 237 (9), 231 (9), 226 (13), 225 (74), 224 (21), 222 (15), 221 (76), 220 (15), 213 (26), 212 (97), 211 (97), 207 (21), 206 (34), 205 (12), 194 (22), 191 (15), 189 (9), 183 (23), 181 (59), 180 (37), 179 (78), 178 (83), 177 (20), 176 (45), 175 (95), 174 (48), 168 (16), 167 (83), 166 (57), 165 (100), 162 (9), 158 (24), 157 (37), 152 (25), 147 (15), 143 (25), 141 (10), 139 (9), 133 (20), 132 (12), 131 (73), 130 (42), 129 (97), 128 (74), 127 (40), 126 (9), 122 (8), 119 (23), 118 (34), 117 (67), 116 (20), 115 (50), 107 (55), 106 (10), 105 (74), 104 (18), 103 (65), 102 (20), 96 (12), 92 (57), 91 (97), 89 (25), 79 (15), 78 (15), 77 (57), 76 (10), 69 (20), 65 (40), 63 (18), 57 (15), 55 (18), 53 (10), 51 (35), 45 (25), 43 (25), 42 (10), 41 (16), 39 (22).

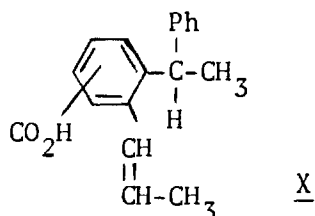
Additional evidence that the major product of the rearrangement was that of phenyl migration was given by the nmr spectrum of the crude acid-II mixture which showed that both allyl and phenyl migration acids were present, see Figure 26.

Reaction (42-II) of 5-Chloro-4,4-diphenyl-1-pentene with Potassium at 65°

In a standard 1000-ml Morton apparatus was condensed 400 ml THF and 1.75 g (0.045 g-atom) of potassium metal was added and the THF

migration may have occurred. This possibility had not been demonstrated before because the percent of phenyl migration in previous lithium reactions had been quite small (1-3%) and was not detected on the vpc columns used for analysis due to the fact the unrearranged acid, 1, and phenyl migration acid, 3, appeared at the same retention time.

refluxed for 1 hr. Stirring was increased as 5.16 g (0.020 mole) of chloride in 20 ml of anhyd THF was added over a 1 min period. Reflux was continued for 3 min after addition of the chloride and the flask was then cooled to ca. room temperature (requiring 3 min) and the solution was forced onto excess crushed Dry Ice. Workup gave 1.18 g of neutral material (not analyzed further) and 3.69 g (68.6% yield) of acidic material. The acidic material was composed of 1.2% diphenylacetic acid (0.695), 2.4% of 2,2-diphenyl-4-pentenoic acid (1.000), 20.3% of 2,2-diphenyl-5-hexenoic acid, 2 (1.266), 11.0% of an unknown compound (1.359) believed to be the double bond isomer of phenyl migration, 2-benzyl-2-phenyl-3-pentenoic acid, 45.8% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.469), and 19.3% of an acid believed to be a benzoic acid derivative, unknown X, (1.945), according to vpc analysis (Column G).



Identification of the 19.3% component acid was made as follows: The methyl esters were collected as they were eluted from the vpc column (Column E) via a 50/50 splitter. The first peak corresponded to added internal standard acid ester. The exact mass was found to be 266.12148 which corresponded to molecular formula $C_{18}H_{18}O_2$. The mass spectrum had ions at 266 (M^+ , < 1), 226 (18), 225 (100), 207 (21), 197 (47), 166 (11), 167 (67), 129 (53), 128 (16), 115 (10), 105 (34), 91 (74), 77 (39), 51 (12), 39 (13). The mass spectrum of the second peak

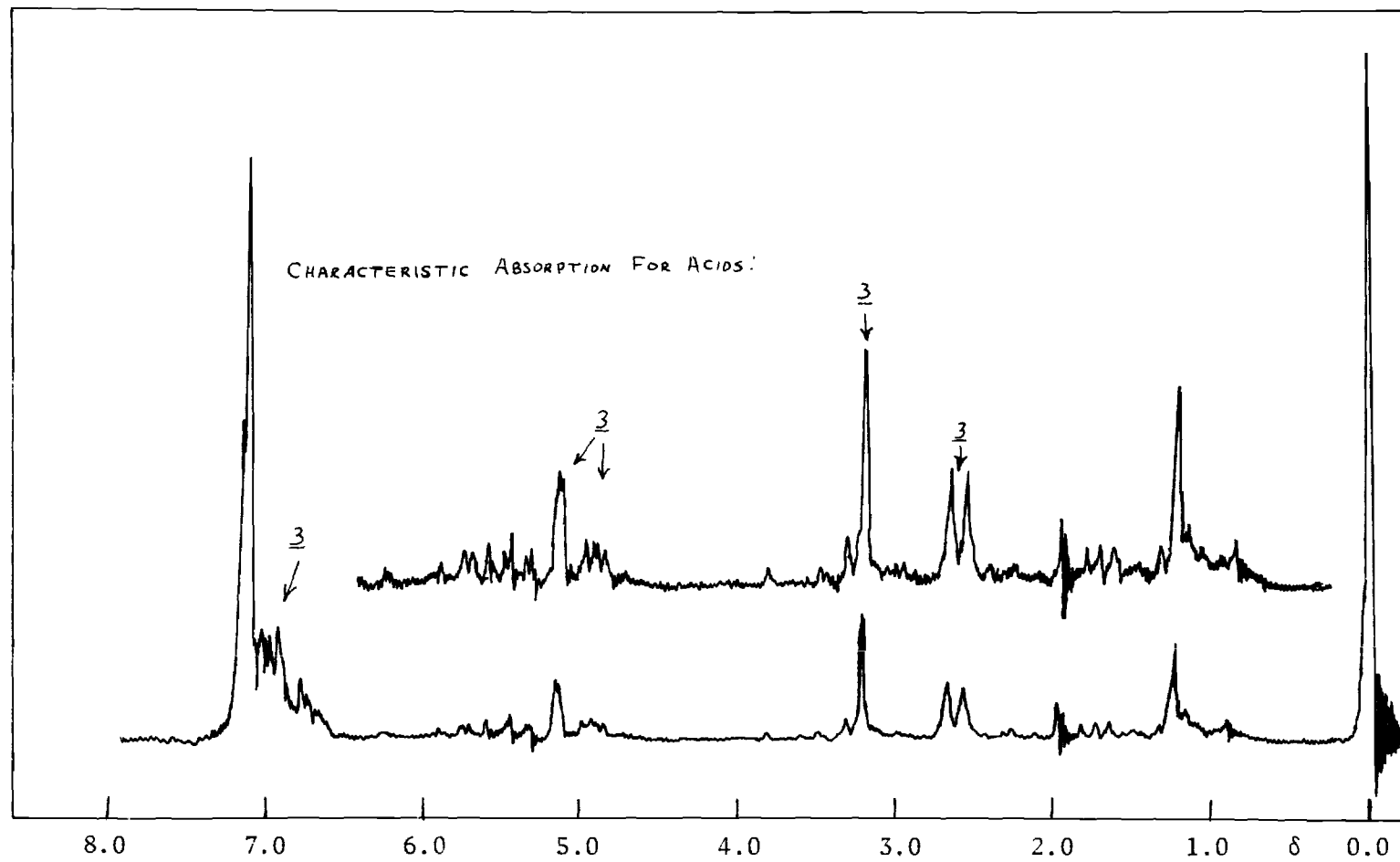


Figure 27. Nmr Spectrum (CS_2) of the Crude Acid from Reaction 42-II

corresponding to allyl migration had ions at 280 (M^+ , < 1), 226 (20), 225 (100), 207 (20), 197, (48), 166 (17), 165 (67), 129 (50), 128 (20), 105 (35), 91 (77), 77 (39), 51 (12), 40 (24).

The third peak corresponding to what is believed to be the double bond-shift isomer of phenyl migration had an exact mass of 280.15150 which corresponded to molecular formula $C_{19}H_{20}O_2$. The mass spectrum had ions at 280 (M^+ , 5), 226 (20), 225 (64), 221 (19), 207 (16), 197 (34), 189 (13), 179 (9), 178 (11), 167 (19), 166 (16), 165 (53), 157 (9), 152 (8), 143 (16), 130 (10), 129 (71), 128 (21), 117 (25), 115 (16), 105 (31), 103 (13), 91 (100), 77 (39), 65 (11), 51 (12), 44 (18), 41 (24). The fourth peak corresponding to phenyl migration had an exact mass of 280.14750 which corresponded to molecular formula $C_{19}H_{20}O_2$. The mass spectrum had ions at 280 (M^+ , 7), 226 (5), 225 (16), 221 (8), 197 (9), 189 (21), 178 (7), 167 (7), 165 (17), 157 (19), 143 (11), 131 (8), 130 (16), 129 (100), 128 (20), 127 (8), 126 (8), 121 (8), 117 (9), 115 (16), 105 (12), 103 (8), 91 (72), 77 (17), 65 (13), 59 (9), 51 (9), 41 (10), 39 (11).

The fifth peak was unknown X and had an exact mass of 280.114832 which corresponded to molecular formula $C_{19}H_{20}O_2$. The mass spectrum had ions at 281 ($M+1$, 5), 280 (M^+ , 23), 225 (7), 221 (8), 220 (7), 219 (6), 205 (8), 193 (23), 189 (18), 179 (8), 178 (12), 165 (10), 161 (6), 157 (12), 143 (29), 131 (10), 130 (13), 129 (69), 128 (26), 127 (10), 121 (18), 117 (7), 116 (6), 115 (33), 105 (15), 103 (8), 102 (6), 92 (10), 91 (100), 89 (7), 77 (16), 71 (8), 65 (16), 59 (11), 51 (10), 44 (8), 43 (6), 41 (11), 40 (10), 39 (11).

Attempts to isolate and purify the 19.3% component acid by

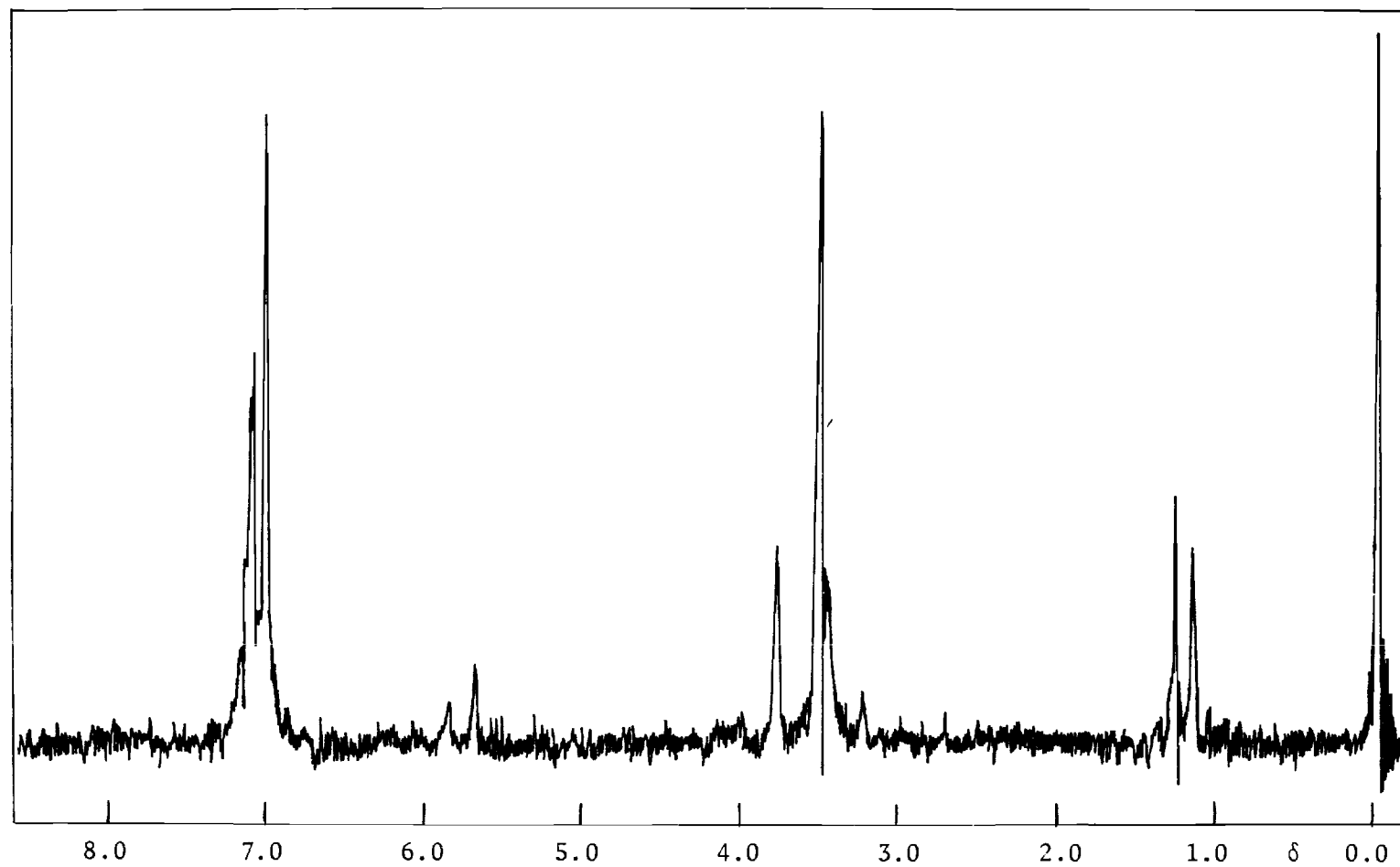


Figure 28. Nmr Spectrum (CS_2) of the 20% Component, i.e., Unknown X (methyl ester) from Reaction 42-II.

chromatography of the free acids on alumina and by high-pressure liquid chromatography on silica gel were unsuccessful. However, the methyl ester was isolated (ca. 6 mg) by extinguishing the flame of the ionization detector and collecting the condensed ester from the effluent gas in a 12" glass tube. The nmr spectrum (CS_2) of the methyl ester had absorption at δ 1.25 (2.4 H, d, $J = 7.0$ Hz, $-\text{CH}_3$), 3.10-3.90 (7.0 H, complex m, $-\text{OCH}_3$, $=\text{CH}-\text{CH}_3$, $-\text{C}(\text{Ph})\text{H}-\text{CH}_3$),* 5.00-6.40 (2.0 H, m, $-\text{CH}=\text{CH}-$), and 6.90-7.30 (8.5 H, complex m, aromatic). The proposed structure of the 19.3% component acid based on vpc retention time, mass spectrum, and nmr spectral analysis is consistent with that of compound X.

Reaction (60-II) of 2,2-Diphenyl-4-pentenyllithium with Lithium tert-Butoxide

In a modified 500-ml Morton apparatus was condensed 250 ml THF after which 6.45 g (0.931 g-atom) of lithium wire was added, followed by 2.28 g (0.016 mole) methyl iodide and 0.88 g (0.009 mole) of n-butyl chloride. The flask was cooled to -75° and 3.90 g (0.015 mole) of chloride in 25 ml anhyd THF was added over a 10 min period; at the end of which, the color of the solution was bright reddish-orange. After 3 hr, a 1-ml aliquot was protonated and vpc analysis showed only one hydrocarbon peak and no chloride remaining. A repeat analysis at 4 hr. gave the same result. A 125-ml aliquot was forced onto excess crushed Dry Ice (carbonation I) after 4.5 hr at -75° . To the remaining solution was added 125 ml (0.159 equivalents of alkoxide) of freshly

*The one proton quartet is hidden but one can distinguish the doublet of the terminal methyl and the singlet of the methoxy function.

prepared lithium tert-butoxide. The solution was stirred 1 min and then a 1-ml aliquot was protonated. (Analysis of the neutral material indicated no change from the previous aliquots taken prior to addition of alkoxide soln). After stirring for 40 min, 125 ml of the carbanion-alkoxide solution was forced onto excess crushed Dry Ice (carbonation II). The remainder of the solution was warmed to 0° and after 30 min a protonated aliquot indicated rearrangement had occurred. Another protonated aliquot 1 hr later gave the same result; therefore, 30 min later the remaining carbanion-alkoxide solution at 0° was forced onto excess crushed Dry Ice (carbonation III).

Workup gave 2.90 g of combined acidic material* for a 71.7% total acid yield. The acid esters (Column G) from carbonation I (1.80 g acid) were composed of 0.6% of 2,2-diphenyl-5-hexenoic acid, 2 (1.271), 91.1% of 3,3-diphenyl-5-hexenoic acid, 1 (1.486), a trace (< 1%) of 2,2-diphenylheptanoic acid (1.563), and 8.3% of an unknown compound (1.771).

The acids of carbonation II (0.60 g acid) were composed (Column G) of 1.6% 2,2-diphenyl-5-hexenoic acid, 2 (1.219), 92.7% of 3,3-diphenyl-5-hexenoic acid, 1 (1.529), a trace (< 1% of 2,2-diphenylheptanoic acid (1.572), and 5.7% of an unknown compound (1.810).

The acids of carbonation III (0.50 g acid) were composed (Column G) of two trace components (0.343 and 0.431) of 2.3% total, 0.9% of diphenylacetic acid (0.686), 0.9% of 2,2-diphenyl-4-pentenoic acid (1.000), 75.1% of 2,2-diphenyl-5-hexenoic acid, 2 (1.255), 3.8% of an

*The neutral material was not analyzed but it can be seen that the total neutral material is on the order of 30% rather than the 50% found in typical reactions without lithium alkoxide added.

unknown acid (1.358), 4.3% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.445), 7.3% of 3,3-diphenyl-5-hexenoic acid, 1 (1.496), 3.4% of 2,2-diphenylheptanoic acid (1.650), and a trace of 2 unknown acids of less than 3% total (2.004 and 2.044).

Reaction (92-II) of 2,2-Diphenyl-4-pentenyllithium with Potassium tert-Butoxide and Cesium tert-Butoxide

In a modified 500-ml Morton apparatus was condensed 250 ml THF after which 8.02 g (1.156 g-atom) of lithium wire was added followed by 1.14 g (0.001 mole) of methyl iodide. After 1 hr at room temperature the flask was cooled to -75° and 0.44 g (0.005 mole) of n-butyl chloride was added and allowed to react for 30 min after which 3.90 g (0.015 mole) of chloride in 10 ml anhyd THF was added over a 5 min period (reaction was noted immediately on addition). After 4.5 hr, a 75-ml aliquot (0.0046 equivalent)* of the carbanion solution at -75° was added (inverse addition) to 75 ml (0.060 equivalents) of potassium tert-butoxide soln in a reaction vessel at -75° . The mixture was shaken to give a homogeneous solution and then was forced onto excess crushed Dry Ice after 10 min reaction time (carbonation I).

A second 75-ml aliquot of the carbanion solution was transferred to a reaction vessel and kept at -75° after which 75 ml (0.060 equivalents) of potassium tert-butoxide soln at -75° was added and the mixture shaken to give a homogeneous solution. The solution was then forced onto excess crushed Dry Ice after 10 min reaction time (carbonation II).

*Assuming 100% carbanion yield and zero protonation by the solvent.

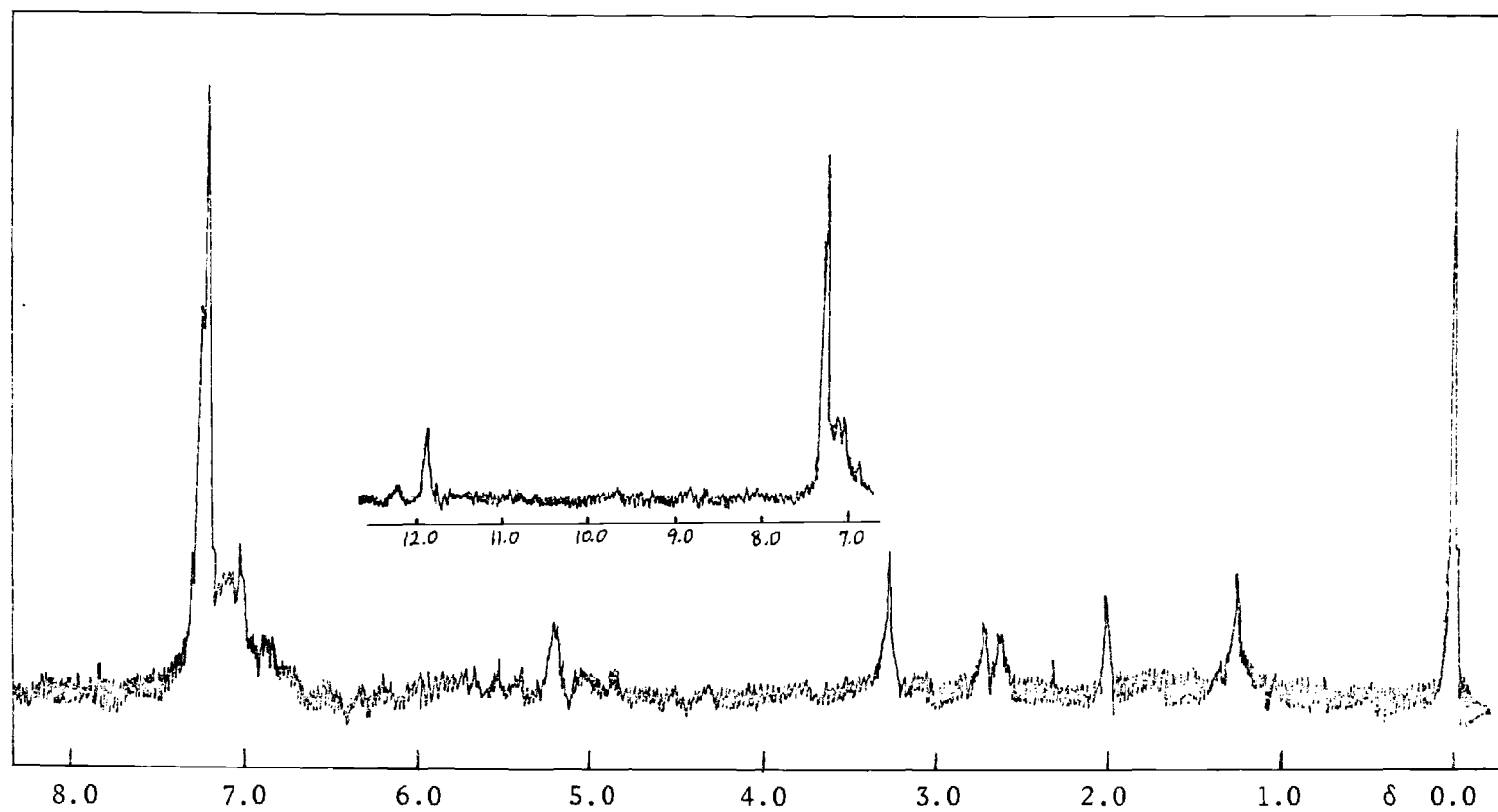


Figure 29. Nmr Spectrum (CS_2) of the III-Crude Acid from Reaction 92-II

A third 75-ml aliquot of the carbanion solution at -75° was added (inverse addition) to a 75 ml (0.060 equivalents) of cesium tert-butoxide soln in a reaction vessel at -75° and the mixture shaken to give a homogeneous solution. The solution was then forced onto excess crushed Dry Ice after 10 min reaction time (carbonation III).

The remaining 20 ml of carbanion solution was forced onto excess crushed Dry Ice after 6 hr of reaction at -75° (carbonation IV).

Workup of carbonation I gave 0.57 g of neutral material and 0.90 g of acidic material. The acidic material (Column F) was composed of a trace of 2,2-diphenyl-4-pentenoic acid (1.000), 26.1% of 2,2-diphenyl-5-hexenoic acid, 2 (1.273), 11.5% of an unknown acid (1.345), 53.2% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.479), 2.7% of 2,2-diphenylheptanoic acid (1.697), and 4.5% of compound X (1.922).

Workup of carbonation II gave 0.50 g of neutral material and 0.88 g of acidic material. The acidic material (Column F) was composed of a trace ($< 1\%$) of 2,2-diphenyl-4-pentenoic acid (1.000), 23.5% of 2,2-diphenyl-5-hexenoic acid, 2 (1.276), 11.4% of an unknown acid (1.348), 56.3% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.486), 4.2% of 2,2-diphenylheptanoic acid (1.712), and 4.5% of compound X (1.931).

Workup of carbonation III gave 0.25 g of neutral material and 1.24 g of acidic material. The acidic material (Column F) was composed of 0.7% of an unknown acid (0.414), 3.3% of diphenylacetic acid (0.687), a trace ($< 1\%$) of 2,2-diphenyl-4-pentenoic acid (1.000), 13.2% of 2,2-diphenyl-5-hexenoic acid, 2 (1.274), 9.8% of an unknown acid (1.342), 67.7% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.476), 1.6% of 2,2-diphenylheptanoic acid (1.702), and 3.7% of compound X (1.920).

Workup of carbonation IV gave 0.08 g of neutral material and 0.24 g of acidic material. The acidic material (Column F) was composed of a trace (< 1%) of 2,2-diphenyl-4-pentenoic acid (1.000), 2.6% of 2,2-diphenyl-5-hexenoic acid, 2 (1.247), 0.9% of an unknown acid (1.354), 86.4% of 3,3-diphenyl-5-hexenoic acid, 1 (1.559), and 10.2% of compound X (1.899).

Reaction (104-II) of 2,2-Diphenyl-4-pentenyllithium with Selected Reagents

In a modified 500-ml Morton apparatus was condensed 250 ml THF after which 5.46 g (0.786 g-atom) of lithium wire was added followed by addition of 0.57 g (0.004 mole) of methyl iodide. The mixture was stirred 10 min at room temperature and then the flask was cooled to -75° and 0.22 g (0.002 mole) of *n*-butyl chloride was added. After stirring for 10 min, 4.01 g (0.015 mole) of chloride in 12 ml of anhyd diethyl ether was added over a 30 min period. After 5 hr, 25-ml aliquots (0.063 mmoles/ml; based on the assumption of 100% yield) of carbanion solution were added to seven reaction vessels containing 25 ml THF and the following: 8.65 g (0.027 g-formula wt) of lithium tetraphenylborate at -75° , 9.50 g (0.027 g-formula wt) of potassium tetraphenylborate at -75° , 3.16 g (0.027 g-formula wt) of potassium bromide at -75° , 7.02 g (0.027 mole) of 18-crown-6-ether* at -75° , 8.65 g (0.027 g-formula wt) of lithium tetraphenylborate at 0° , 7.03 g (0.027 mole) of 18-crown-6-ether at 0° , and a blank at 0° . The remaining carbanion solution was forced onto excess Dry Ice (carbonation I).

*The solubility of 18-crown-6-ether in THF at -75° was found to be 6 g/100 ml THF by R. E. Williamson. The density of liquid 18-crown-6-ether at 23° was found to be 1.11 g/ml by the author.

The various reactions at -75° and 0° were allowed to stand under nitrogen for 3 hr after which each was forced onto excess crushed Dry Ice. Unfortunately, only four of the reaction carbonation products gave acid on workup. The -75° blank reaction gave essentially (> 90 area %) of 3,3-diphenyl-5-hexenoic acid, 1; the 0° blank gave essentially (> 90 area %) of 2,2-diphenyl-5-hexenoic acid, 2; and the -75° 18-crown-6-ether and -75° KBr reaction both gave essentially (> 90 area %) of 3,3-diphenyl-5-hexenoic acid, 1. The other reactions with added $\text{Li}\phi_4\text{B}$, $\text{K}\phi_4\text{B}$, and 18-crown-6-ether at 0° were prematurely quenched by an unknown source.

Reaction (134-I) of 2,2-Diphenyl-4-pentenyl-3- ^{14}C -lithium at -32°

In a standard 500-ml Morton apparatus was condensed 250 ml of THF after which 1.85 g (0.267 g-atom) of lithium wire was added followed by 3.42 g (0.024 mole) of methyl iodide. The flask was cooled to -75° for 10 min and then 4.64 g (0.018 mole) of ^{14}C -chloride* with 2.28 g (0.161 mole) of methyl iodide was added in 50 ml of THF over a 10 min period. Protonation of 1-ml aliquots of the carbanion solution with water showed only 5.4% of unreacted chloride remained after 5.5 hr. After 8.5 hr, 100 ml of the solution was forced onto excess crushed Dry Ice (carbonation I). The remainder of the solution was warmed to $-32^{\circ} \pm 3^{\circ}$ for 3 hr and then was forced onto excess crushed Dry Ice (carbonation II).

Workup of carbonation I gave 2.70 g of acidic material (Column H) composed of 7.5% diphenylacetic acid** (10.4 min), 4.9% of 2,2-diphenyl-

*Specific activity = 0.427 ± 0.024 $\mu\text{C}/\text{mmole}$.

**Believed to be due to a trace of diphenylmethane in the starting chloride.

propanoic acid* (10.8 min), 2.4% of 2,2-diphenyl-4-pentenoic acid (13.0 min), 1.2% of 2,2-diphenyl-5-hexenoic acid, 2 (14.4 min), and 83.9% of 3,3-diphenyl-5-hexenoic acid, 1 (16.0 min). Carbonation II (Column H) gave 3.67 g of acidic material composed of 1.3% of diphenylacetic acid (10.4 min), 3.3% of 2,2-diphenylpropanoic acid (10.8 min), 6.6% of 2,2-diphenyl-4-pentenoic acid (12.8 min), 68.8% of 2,2-diphenyl-5-hexenoic acid, 2 (14.6 min), and 18.8% of 3,3-diphenyl-5-hexenoic acid, 1 (16.0 min).

The bulk acidic material of carbonation II was esterfied with dizaomethane and the esters were separated on a 10" x 1" dia acid washed alumina column by eluting with cyclohexane with increasing increments of benzene. The first fractions were enriched with the product of allyl migration, 2-ester, while the latter were enriched with unrearranged product, 1-ester. The allyl migration ester (98 area % purity by vpc) was ozonized in chloroform at -50° . After reductive workup, the mixture was added to 2.1 equivalents of methone in 95% ethanol to make the formaldehyde methone derivative. The methone derivative was isolated by crystallization from 95% ethanol and the radioactivity was determined.

Due to experimental difficulties, two methods of counting were employed. The radioactive count was determined by both liquid scintillation and/or by combustion to CO_2 and then counting by the vibrating reed electrometer (VRE) methods. The allyl migration product ester had a specific activity of $0.438 \pm 0.002 \text{ } \mu\text{C}/\text{mmole}$ (VRE- 0.457 ± 0.015

*Believed to be due to a trace of 1,1-diphenylethane in the starting chloride.

$\mu\text{C}/\text{mmole}$) while the methone derivative had a count of 0.272 ± 0.001 $\mu\text{C}/\text{mmole}$ (VRE- 0.291 ± 0.001 $\mu\text{C}/\text{mmole}$).

Reaction (3-II) of 2,2-Diphenyl-4-pentenyl-3- ^{14}C -lithium at 0°

In a modified 500-ml Morton apparatus was condensed 250 ml of THF after which 1.30 g (0.187 g-atom) of lithium wire was added followed by 2.28 g (0.161 mole) of methyl iodide. The flask was stirred for 30 min, cooled to -75° , and then 0.88 g (0.009 mole) of *n*-butyl chloride was added and stirred for 1 hr. The addition of 4.51 g (0.018 mole) of "diluted" ^{14}C -chloride* in 10 ml of anhyd THF was completed over a 5 min period. Reaction of the chloride was observed after stirring for 2.75 hr (slow initiation).

Aliquots of the carbanion solution were protonated by water with time. Analysis of the neutral material showed the chloride was completely reacted after 12 hr at -75° ; thereupon, a 75-ml aliquot was forced onto excess crushed Dry Ice (carbonation I). The remainder of the solution was warmed to $0^\circ \pm 2^\circ$ and was allowed to react for 2.5 hr after which the solution was forced onto excess crushed Dry Ice (carbonation II).

Carbonation I gave 1.17 g of neutral material and 0.91 g of acidic material. The acidic material (Column C) was composed of a trace of 2,2-diphenyl-4-pentenoic- ^{14}C acid (6.2 min), 94.3% of 3,3-diphenyl-5-hexenoic- ^{14}C acid, 1 (8.2 min), and 5.7% of an unknown (9.9

*The ^{14}C -chloride prepared and used initially (i.e., 134-I) had a total specific activity of 0.427 ± 0.024 $\mu\text{C}/\text{mmole}$. All other radioactive reactions were carried out using "diluted" chloride (original chloride diluted with "cold" chloride) with a specific activity of 0.306 ± 0.002 $\mu\text{C}/\text{mmole}$.

min). The acid product was crystallized from pentane to give 0.26 g of vpc pure (Column C) acid crystals of mp 90.5°-91.5° which gave a mixture mp 105.0°-106.0° with authentic 3,3-diphenyl-5-hexenoic acid (mp 105.0°-106.0°). The specific activity of the total acid was $0.289 \pm 0.002 \mu\text{C}/\text{mmole}$ (VRE- $0.290 \pm 0.003 \mu\text{C}/\text{mmole}$) while the methone derivative from the formaldehyde produced via ozonization had a specific activity of $0.004 \pm 0.001 \mu\text{C}/\text{mmole}$ (VRE- $0.004 \pm 0.001 \mu\text{C}/\text{mmole}$).

Carbonation II gave 2.07 g of neutral material and 1.36 g of acidic material. The acidic material (Column G) was composed of 88.9% 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2 (1.257), 2.1% of 2-benzyl-2-phenyl-4-pentenoic acid, 3 (1.434), 2.1% of 3,3-diphenyl-5-hexenoic acid, 1 (1.516), and 6.9% of 2,2-diphenylheptanoic acid (1.658). The acid was recrystallized twice from 95% ethanol-water to give 0.5 g of acid of > 98% purity and mp 134.0°-135.0°. The specific activity of the total acid was $0.283 \pm 0.001 \mu\text{C}/\text{mmole}$ (VRE- $0.288 \pm 0.006 \mu\text{C}/\text{mmole}$) while the methone derivative from the formaldehyde produced via ozonization had a specific activity of $0.155 \pm 0.005 \mu\text{C}/\text{mmole}$ (VRE- $0.150 \pm 0.003 \mu\text{C}/\text{mmole}$). However, the methone derivative from the formaldehyde produced via OsO_4 oxidation had a specific activity of $0.197 \pm 0.001 \mu\text{C}/\text{mmole}$.
Reaction (112-II) of 2,2-Diphenyl-4-pentenyl-3- ^{14}C -lithium at -50°

In a modified 500-ml Morton apparatus was condensed 210 ml of THF and then 7.26 g (0.047 g-atom) of lithium wire was added, followed by 1.14 g (0.008 mole) of methyl iodide. The flask was stirred for 30 min and then cooled to -75°. Addition of 5.18 g (0.020 mole) of diluted ^{14}C -chloride in 10 ml THF was completed over a 40 min period; reaction was observed immediately on addition. After 4.5 hr of reaction at -75° the red solution was forced over to a reaction vessel which had

been flame dried and was in a large Dewar at -75° .* The reaction vessel was then transferred to a -50° thermostatted circulator bath** and a 20-ml aliquot was forced onto excess crushed Dry Ice (carbonation I). The remainder of the carbanion solution was kept at $-50^{\circ} \pm 0.5^{\circ}$ for 96.5 hr and then was forced onto excess crushed Dry Ice (carbonation II).

Carbonation I gave 0.44 g of acidic material*** (Column F) composed of a trace ($< 1\%$) of 2,2-diphenyl-4-pentenoic- ^{14}C -acid (1.000), 7.0% of 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2 (1.263), 89.7% of 3,3-diphenyl-5-hexenoic- ^{14}C acid, 1 (1.536), and 3.3% of an unknown (1.857).

Carbonation II gave 2.76 g of acidic material*** (Column F) composed of a trace ($< 1\%$) of 2,2-diphenyl-4-pentenoic- ^{14}C -acid (1.000), 90.8% of 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2 (1.267), 3.7% of 2-benzyl-2-phenyl-4-pentenoic- ^{14}C acid, 3 (1.465), and 5.5% of 3,3-diphenyl-5-hexenoic- ^{14}C acid, 1 (1.510). The acid product was recrystallized from 95% ethanol-water once and methanol-water twice to give 0.99 g of (99% purity, Column E) 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2, mp 134.0° - 135.0° . The specific activity of the total acid was 0.286 ± 0.002 $\mu\text{C}/\text{mmole}$ (VRE-0.284 $\mu\text{C}/\text{mmole}$ --error limits uncertain) while the methone derivative from the formaldehyde produced via ozonization had a specific activity of 0.201 ± 0.002 $\mu\text{C}/\text{mmole}$ (VRE-0.166 $\mu\text{C}/\text{mole}$ --error limits uncertain). However, the methone derivative from the formaldehyde produced via OsO_4 oxidation had a specific activity of 0.237 ± 0.002 $\mu\text{C}/\text{mmole}$ (VRE-0.195 $\mu\text{C}/\text{mmole}$ --error limits uncertain).

The aqueous-ethanolic mother liquor from the methone derivative

*Designed and loaned by R. E. Williamson.

**Lauda K-2/R circulator bath with Dry Ice-heat exchanger attached.

***The neutral material was not analyzed further.

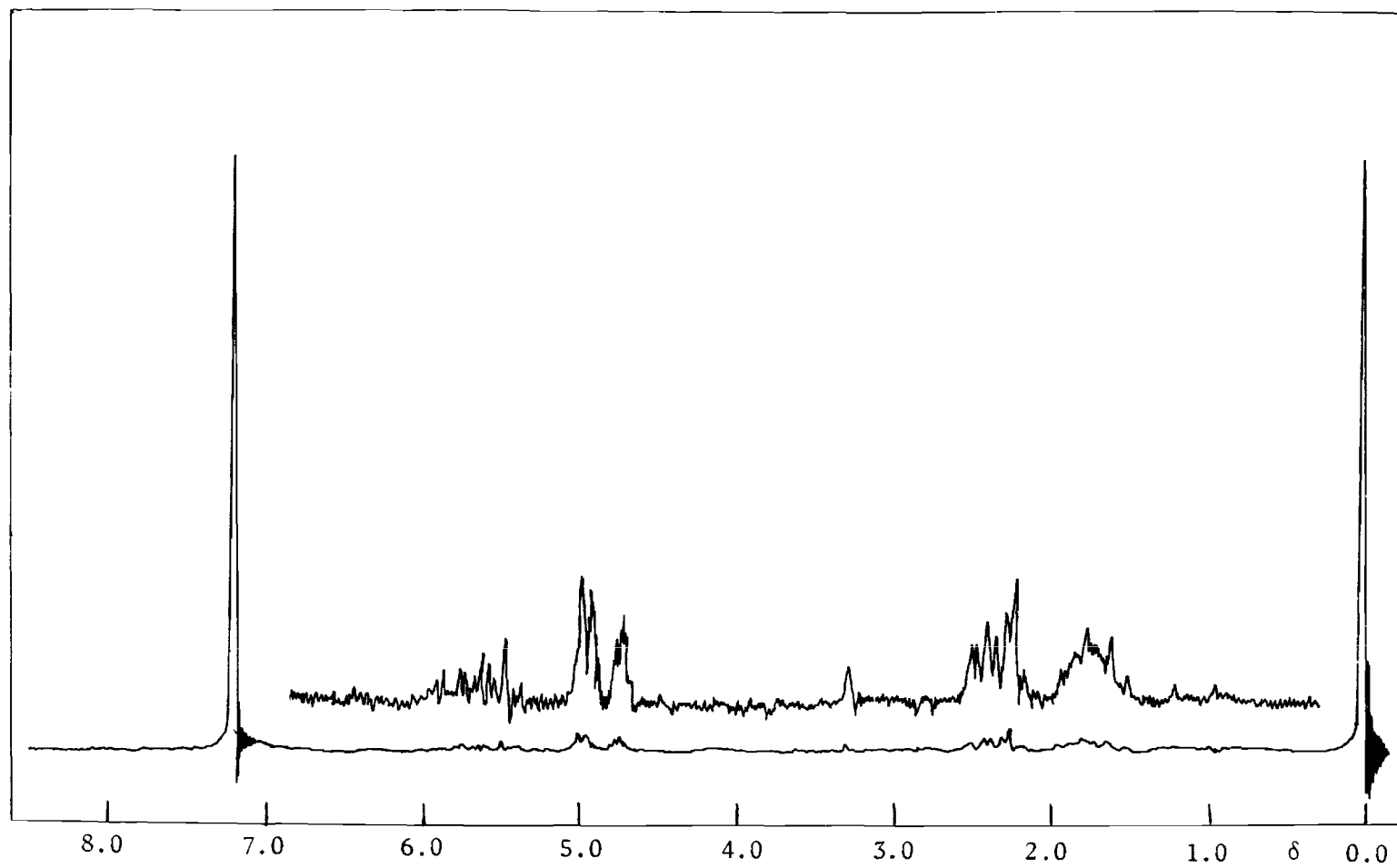


Figure 30. Nmr Spectrum (CS_2) of II-Acid Crystals (mp 134.0° - 135.0°) from Reaction 112-II

(via ozone oxidation of the ester) preparation was reduced in volume and 40 ml of ether was added. The ether extract was washed with 20 ml water and then was dried over anhyd MgSO_4 . The dried ether extract was then reduced in volume to ca. 5 ml and was added to a fresh 2,4-dinitrophenylhydrazine soln. The 2,4-DNP derivative of the ozone terminal methylene cleavage was recrystallized from 95% ethanol to give red-orange crystals mp 170.0° - 172.0° . The specific activity was (VRE) $0.046 \mu\text{C}/\text{mmole}$.

Anal. (Atlantic) Calcd for $\text{C}_{24}\text{H}_{22}\text{O}_6\text{N}_4$: C, 62.33; H, 4.80; O, 20.76; N, 12.12. Found: C, 62.04, 62.05; H, 4.87, 4.87; N, 12.28, 12.32.

The 2,4-DNP derivative of the acid residue in the ether phase from the OsO_4 oxidation of the allyl migration acid was prepared (Chapter III). The derivative was recrystallized from 95% ethanol to give yellow crystals of mp 203.0° - 204.0° . The specific activity was (VRE) $0.043 \mu\text{C}/\text{mmole}$.

Anal. (Atlantic) Calcd for $\text{C}_{23}\text{H}_{20}\text{O}_6\text{N}_4$: C, 61.60; H, 4.50; O, 21.41; N, 12.49. Found: C, 61.33, 61.38; H, 4.61, 4.59; N, 12.36, 12.38.

Reaction (4-III) of 2,2-Diphenyl-4-pentenyl-3- ^{14}C -lithium with Potassium tert-Butoxide:18-Crown-6-ether Complex at -75°

In a modified 500-ml Morton apparatus was condensed 125 ml of THF and then 5.51 g (0.794 g-atom) of lithium wire was added, followed by 1.14 g (0.008 mole) of methyl iodide. The flask was stirred for 30 min and then cooled to -75° . Addition of 3.82 g (0.015 mole) of diluted ^{14}C -chloride in 25 ml of anhyd THF was completed over a 10 min

period and reaction was observed 5 min after the addition was completed. After 4 hr of reaction, a double Gilman titration showed that ca. 0.007 equivalents of carbanion was present (i.e., 50% yield) and a 10 ml aliquot was forced onto excess crushed Dry Ice (carbonation I). The complex was prepared by adding 125 ml (0.078 equivalents) of freshly prepared potassium tert-butoxide to 20.8 g (0.079 mole) of freshly distilled 18-crown-6-ether under nitrogen in a 200-ml Erlenmeyer flask at room temperature. A small amount of white ppt formed on mixing the reagents to prepare the complex but slight warming effected complete solution. To the carbanion solution after 6.5 hr of reaction at -75° , the clear purple-gray-brown complex was added by a 100-ml syringe (50 ml) while the remaining 75 ml was added from a pressure-equalizing drop funnel dropwise with stirring over 15 min so that the temperature was $-70^{\circ} \pm 2^{\circ}$ throughout the addition. Immediately after addition of the complex, a 10-ml aliquot was forced onto excess crushed Dry Ice (carbonation II) while the remaining bulk of the reaction mixture was stirred at -75° for an additional 30 min and then was forced onto excess crushed Dry Ice (carbonation III).

Carbonation I gave 0.2 g of acidic material (Column F) composed of a trace ($< 1\%$) of 2,2-diphenyl-4-pentenoic- ^{14}C acid (1.000), 3.3% of 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2 (1.233), 95.6% of 3,3-diphenyl-5-hexenoic- ^{14}C acid, 1 (1.526), and 1.0% of compound X (1.796). Hydrolysis of the ester (5% KOH in ethanol) gave the free acid 1, on workup. Crystallization of the acid from pentane gave 0.11 g of acid mp 101.0° - 103.0° which was $> 95\%$ pure by vpc. The specific activity*

*The specific activity of this acid is somewhat low (0.287 ± 0.003)

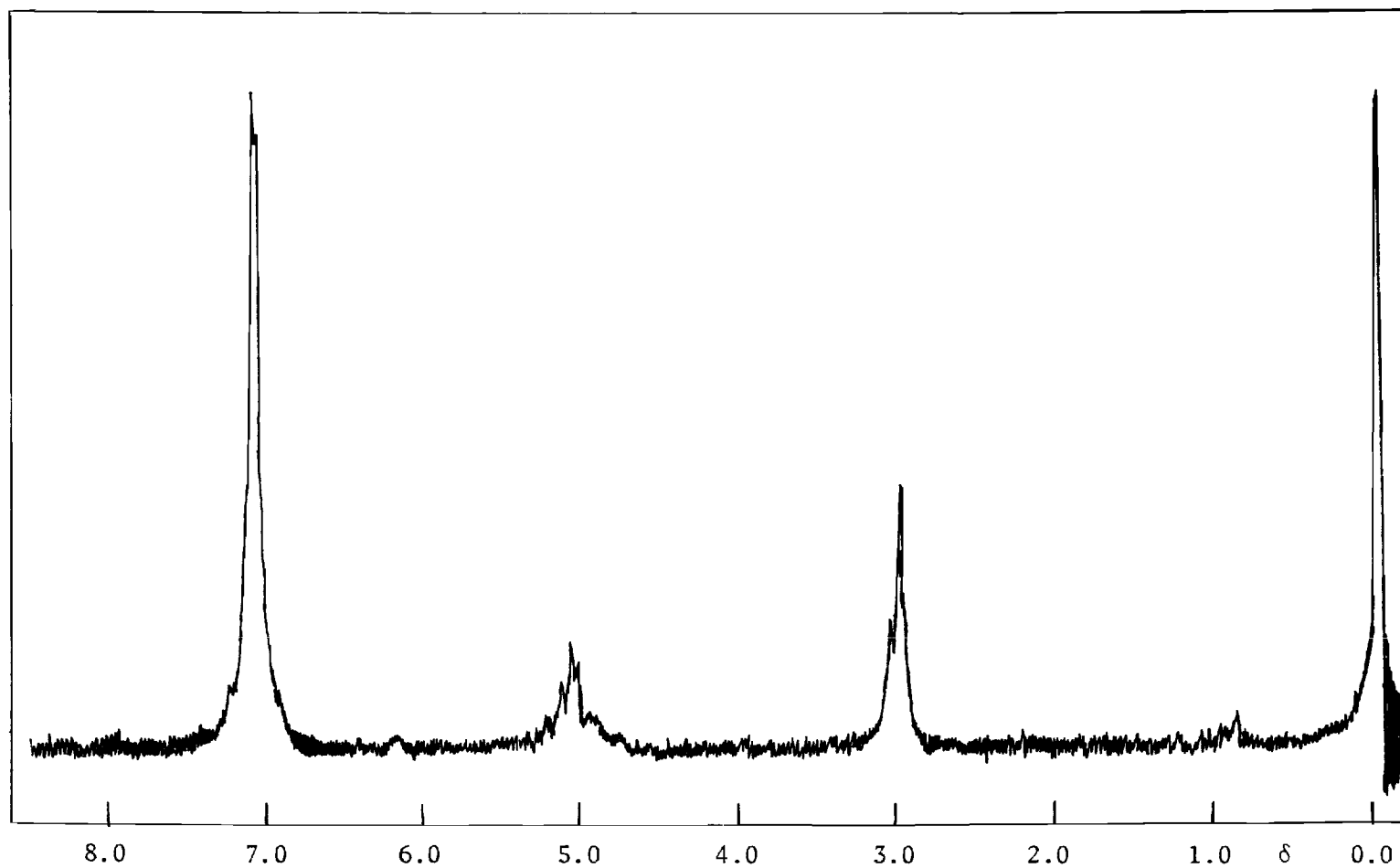


Figure 31. Nmr Spectrum (CS_2) of I-Acid from Reaction 4-III

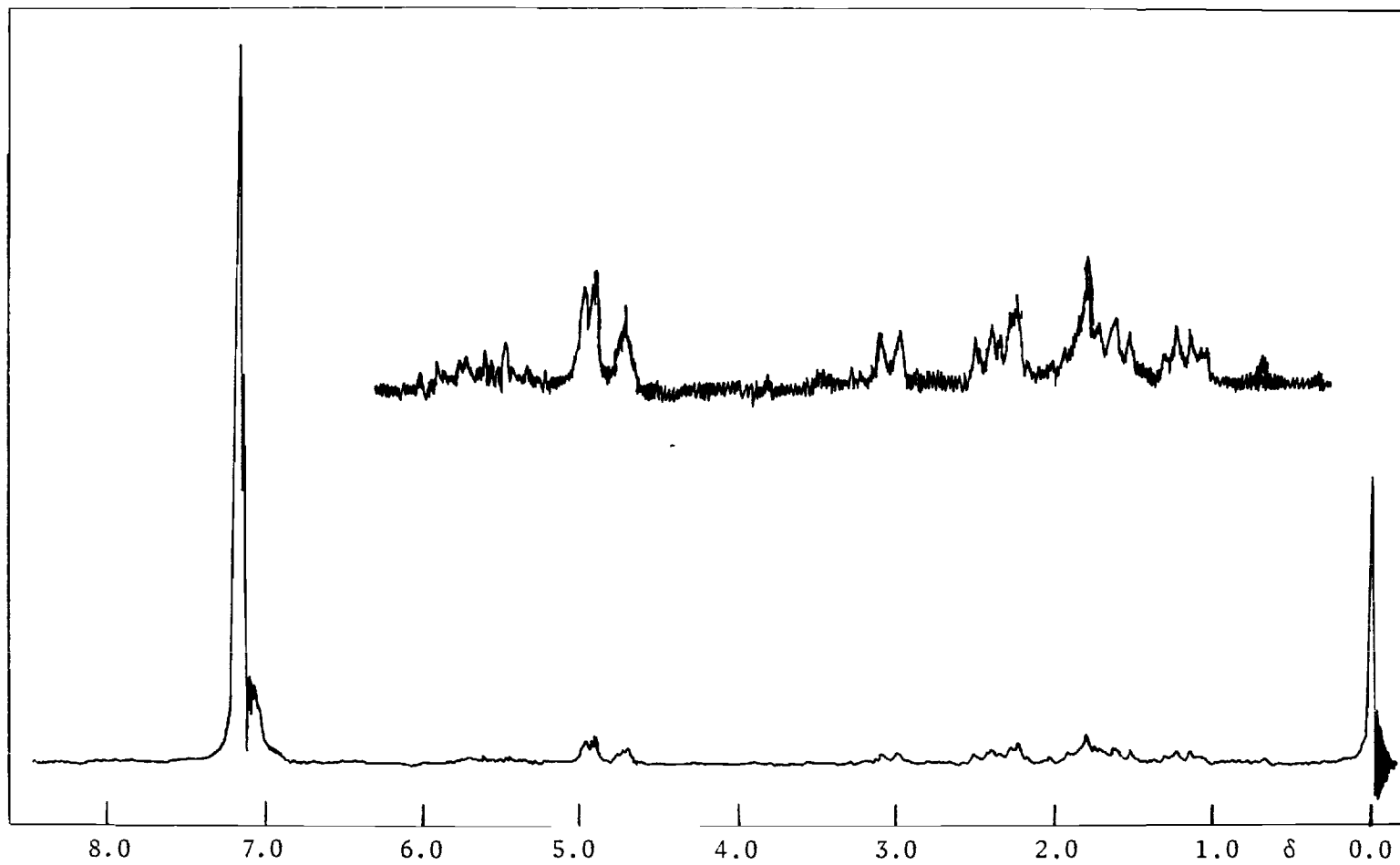


Figure 32. Nmr Spectrum (CS_2) of III-Crude Acid from Reaction 4-III

of the acid was 0.287 ± 0.003 $\mu\text{C}/\text{mmole}$.

Carbonation II gave 0.03 g of acidic material and was of the same composition (Column F) as was carbonation III. Carbonation III gave 1.88 g of neutral material and 0.77 g of acidic material. The acidic material (Column F) was composed of 1.6% of diphenylacetic acid (0.576), 6.0% of 2,2-diphenylpropanoic acid (0.696), 28.0% of 2,2-diphenyl-4-pentenoic- ^{14}C acid (1.000),* 53.4% of 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2 (1.272), 8.6% of 2-benzyl-2-phenyl-4-pentenoic- ^{14}C acid, 3 (1.464), and 2.3% of compound X (1.880).

Separation of the acid III mixture was attempted by converting the acids to the corresponding methyl esters and eluting with cyclohexane on a 10" x 1" dia column of acid-washed alumina but sufficient separation was not accomplished. Then, the fractions containing the greater amount of the desired 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2, were combined and separation was achieved by the previous prep vpc technique. The acid, 2-ester, obtained in 99% purity was hydrolyzed by refluxing the ester with 10 ml of 5% KOH in absolute ethanol for 29 hr. The acid obtained began to crystallize (mp was not taken, nor was specific

$\mu\text{C}/\text{mmole}$) when compared to that of the starting chloride (0.306 ± 0.002 $\mu\text{C}/\text{mmole}$) and the corresponding acid of allyl rearrangement from carbonation II (0.303 ± 0.004 $\mu\text{C}/\text{mmole}$). This may be explained by the fact it is more difficult to purify the unrearranged acid (1) by recrystallization than the acid (2) corresponding to allyl migration. On the other hand, the higher values could be due to lower molecular weight isotopic impurities in the chloride or rearranged acid.

*The large amount of 2,2-diphenyl-4-pentenoic- ^{14}C acid found was attributed to the increased basicity of the reaction system due to the presence of 18-crown-6-ether whereby the presence of a 5% hydrocarbon impurity in the chloride (4,4-diphenyl-1-butene) could in effect be magnified relative to other potential carbanions.

activity measured) when the ether was removed. The acid was dissolved in 10 ml ether and oxidized by $\text{OsO}_4\text{-2NaIO}_4$ to finally give the methone formaldehyde derivative which had a specific activity of 0.303 ± 0.004 $\mu\text{C}/\text{mmole}$.

Reaction (134-II) of 2,2-Diphenyl-4-pentenyllithium with Allyl- ^{14}C -lithium at 0°

In a modified 500-ml Morton apparatus was condensed 150 ml of THF and then 5.73 g (0.826 g-atom) of lithium wire was added followed by 1.14 g (0.008 mole) of methyl iodide. After 15 min, the flask was cooled to -75° and 3.98 g (0.015 mole) of diluted ^{14}C -chloride in 25 ml of anhyd THF was added over a 30 min period. After 3.5 hr, a double Gilman titration was carried out and indicated 0.008 equivalents of carbanion present for a 50% yield. A 25-ml aliquot of the carbanion solution was forced onto excess crushed Dry Ice after 4.25 hr (carbonation II). Then to the remaining solution 125 ml (0.044 equivalents) of freshly prepared allyl- ^{14}C -lithium* was added and mixed at -75° . After 20 min at -75° , a 25-ml aliquot of the "carbanion"-allyllithium solution was forced onto excess crushed Dry Ice (carbonation III) and the remaining solution was then warmed to $0^\circ \pm 5^\circ$. The solution was kept at 0° for 3.25 hr and then was forced onto excess crushed Dry Ice (carbonation IV).

Workup of carbonation II gave 0.98 g of acidic material (Column E) composed of 3.0%, 2,2-diphenyl-4-pentenoic acid (1.000), 1.0% of

*A 25-ml aliquot of the allyl- ^{14}C -lithium preparation was carbonated (carbonation I) prior to addition to the "carbanion" solution. The p-phenylphenacyl ester of n-butyric acid (vinyl acetic acid + H_2) was prepared.

2,2-diphenyl-5-hexenoic acid, 2 (1.090), 1.7% of an unknown (1.189), 85.1% of 3,3-diphenyl-5-hexenoic acid, 1 (1.369), and two unknowns (1.622 and 1.901) of 7.9% and 1.3%.

Carbonation III was acidified with 50 ml of 1 N HCl and the organic material was extracted with 50 ml of ether. The ether extract was treated with 10% NaOH twice and washed with water to remove the acidic material. The aqueous layer was acidified and the free acids extracted with 150 ml of ether to give 1.56 g of acidic material (Column E) composed of 2.7% of 2,2-diphenyl-4-pentenoic acid (1.000), 1.6% of an unknown (1.187), 86.2% of 3,3-diphenyl-5-hexenoic acid, 1 (1.357), and 9.6% of an unknown (1.625).

Carbonation IV workup was somewhat more tedious in that it was necessary to separate vinylacetic-¹⁴C acid from the other product acids of higher molecular weight. Thus, the carbonation residue was acidified and the organic material was extracted with ether. The ether extract was then treated twice with 10% NaOH and washed with water to remove the acidic material. The combined aqueous layer was acidified with HCl and extracted with 200 ml of ether. This ether extract which contained all the acidic material was washed with 200 ml of 10% NaHCO₃ followed by water. The NaHCO₃ extract* was acidified slowly with HCl and then extracted with 150 ml of ether and allowed to stand overnight. The bulk of the ether was distilled from the ethereal extract through

*Vinylacetic acid was more soluble in slightly alkaline aqueous soln than were the higher molecular weight acids which required a stronger base (NaOH) to keep the basic salts of the carboxylic acids in the aqueous phase.

a microdistillation apparatus at 25°-26° at 100 μ and collected in a dual receiver trap which was cooled to -75°. The distillate in the receivers was combined (2.52 g) and then reduced catalytically by hydrogen (0.019 mole uptake). One half of the n-butyric acid soln was used to make the p-phenylphenacyl ester. Titration of the acid soln with 0.1 N NaOH to make the sodium salt followed by refluxing in aqueous-ethanol solution with 2.67 g of p-phenylphenacylbromide at room temperature overnight and then with stirring at reflux for 1 hr before cooling the next day gave the desired derivative. The reaction mixture was cooled and shiny-beige crystals began forming. The crystals (1.61 g) were collected and washed with 95% ethanol-water, (2:1, v/v). The crystals (mp 78.5°-80.0°) were recrystallized from 95° ethanol-water to give 0.61 g of silvery crystals mp 80.5°-81.0° which were pure according to vpc (Column C) and nmr analysis. The specific activity of the p-phenylphenacyl ester of butanoic-¹⁴C acid was 0.199 ± 0.001 μ C/mmole.

The ether extract residue of the previous NaHCO₃ extraction was treated with 10% NaOH, followed by water, acidified by HCl, and then extracted with ether. The ethereal soln was dried over anhyd MgSO₄ and concentrated to give 2.74 g of acid which crystallized on standing in the cold. The crude acidic material (Column E) was composed of 5.3% of 2,2-diphenyl-4-pentenoic-¹⁴C acid (1.000), 85.0% of 2,2-diphenyl-5-hexenoic-¹⁴C acid, 2 (1.083), 9.7% of an unknown (1.266), and a trace (< 1% each) of three other components (1.679, 1.899, and 2.275). The crystals were broken up, transferred to an Erlenmeyer flask and were recrystallized from a MeOH-water mixture to give 1.23 g

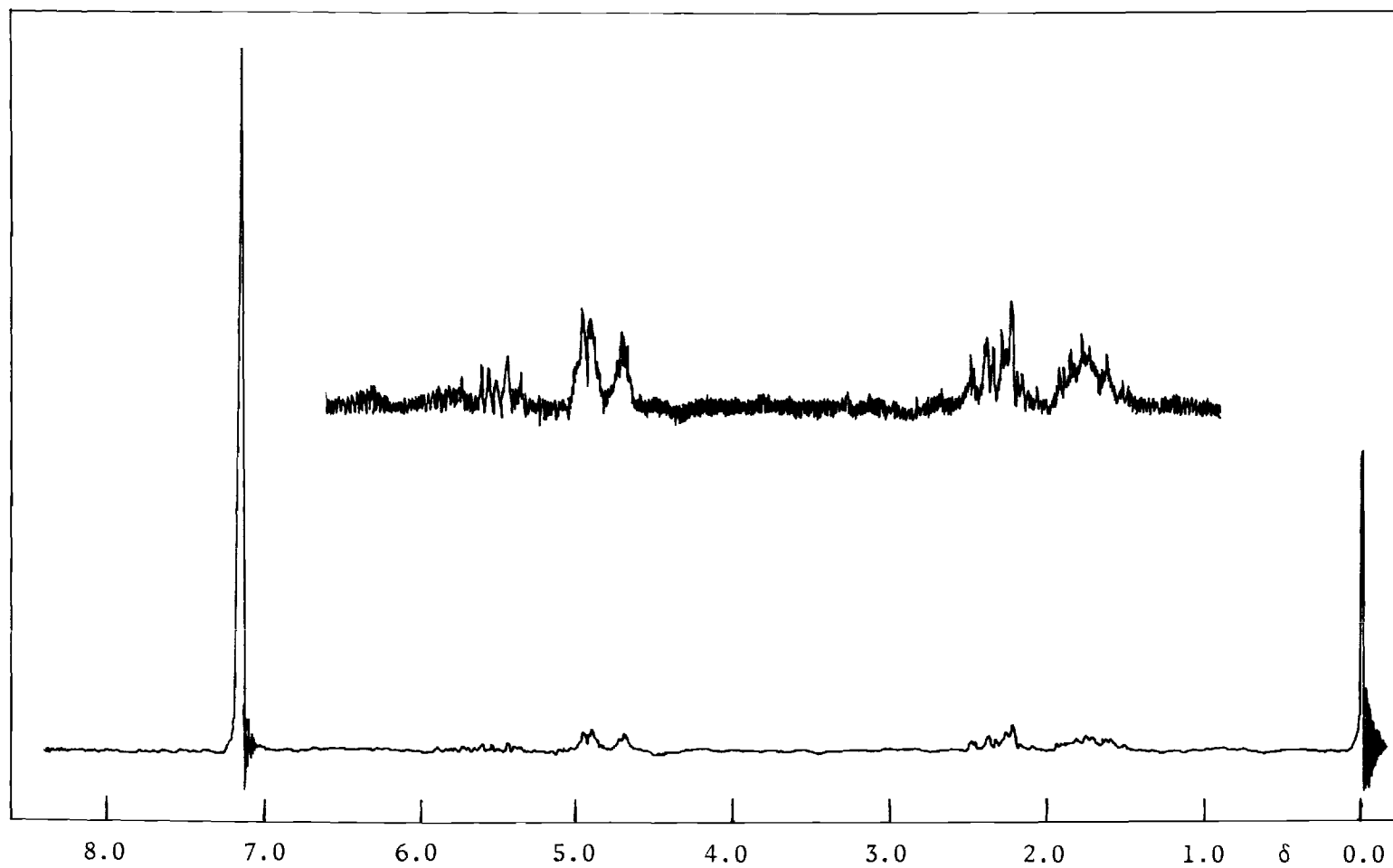


Figure 33. Nmr Spectrum (CS₂) of IV-Acid (mp 137.0°-138.0°) from Reaction 134-II

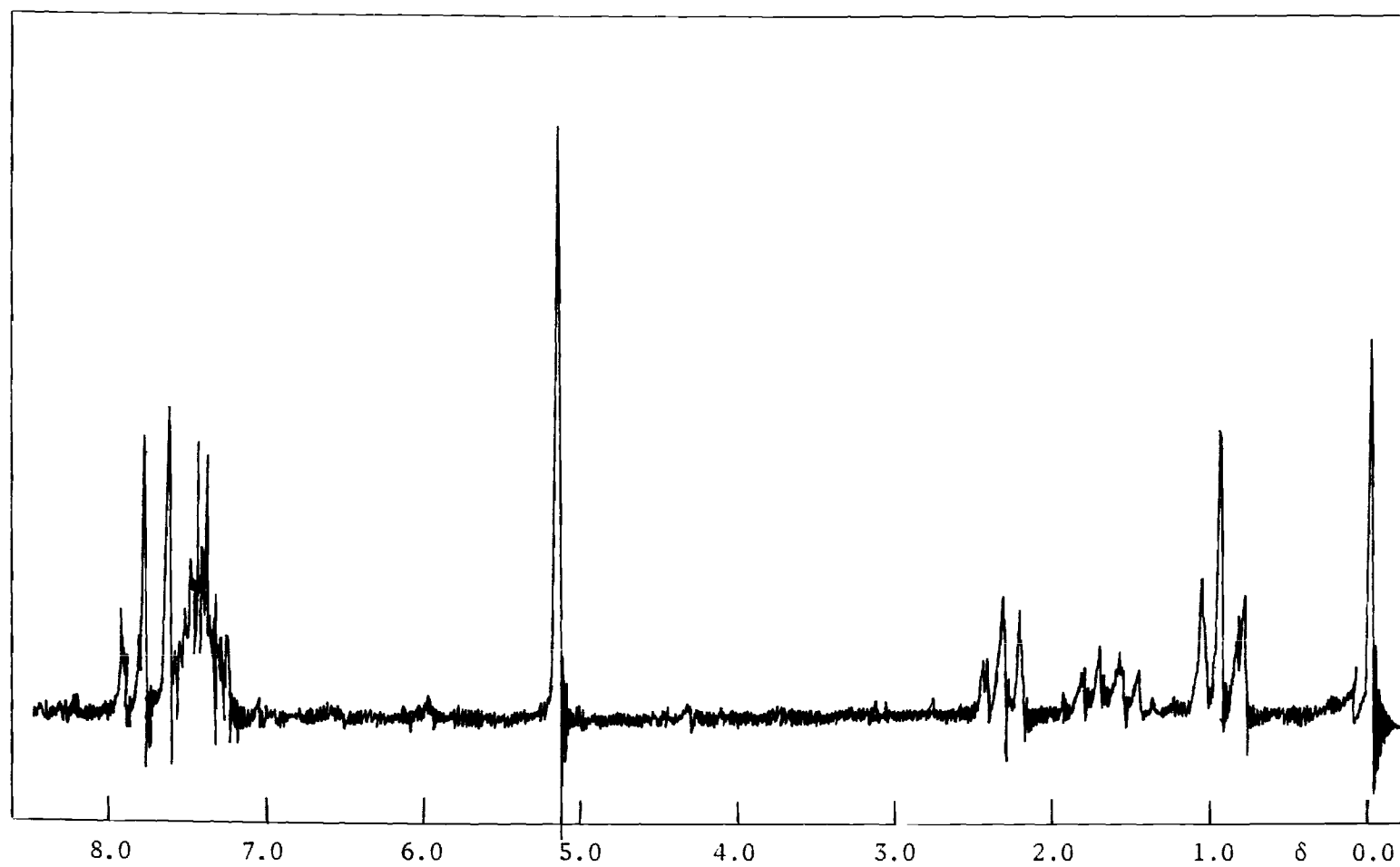


Figure 34. Nmr Spectrum (CS_2) of IV-p-Phenylphenacyl Ester of Butyric Acid (134-II)

of acid mp 136.0° - 137.0° . A repeat recrystallization gave 0.93 g of 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2, of mp 137.0° - 138.0° . The recovered 2,2-diphenyl-5-hexenoic- ^{14}C acid (97% pure, Column E) had a specific activity of $0.0261 \pm 0.001 \mu\text{C}/\text{mmole}$.

C.I.D.N.P. Experiment with 2,2,3-Triphenylpropyllithium (124-I)

In a four-neck 100-ml Morton apparatus in a dry box with nitrogen atmosphere was condensed 75 ml of THF after which 0.69 g (0.100 g-atom) of lithium wire was added at -70° followed by 1.14 g (0.009 mole) of methyl iodide. The flask was in a iso-octane bath which was cooled by a liquid nitrogen flow through a coil. Five to 10% of the chloride solution containing 4.08 g (0.011 mole) of 1-chloro-2,2,3-triphenylpropane and 1.14 g (0.008 mole) of methyl iodide in 10 ml of THF was added. In 10 minutes a pink color was noted which deepened to red after 20 minutes at -50° to -70° . The remainder of the chloride solution was then added over a 10 minute period with a 5 ml THF wash. The color became lighter and then a blueish-red to deep violet-red developed after 5 min. Moderate stirring was maintained as it appeared the reaction was complete after one hour. Gilman titration indicated the reaction was complete after 3 hr and thus 1-ml samples (14) were withdrawn by syringe, transferred to nmr tubes, and then were placed in the -70° bath. The nmr tube tops were sealed in the nitrogen atmosphere by epoxy cement and then were transferred to a Dry Ice-acetone bath so that the samples could be taken to the nmr room and the spectrum scanned.

The tubes were removed from the -78° bath and wiped free of solvent and inserted immediately into the A-60D probe at $+40^{\circ}$. Rapid

scans (50 and 100 sec sweep--normal 500 cps and 1000 cps scans) were run intermittently (generally at one minute intervals as soon as the sample was introduced). No inverted peaks from emission or decreased absorption were observed, but of course this effect could have been masked by THF absorption or could have been completed prior to complete scanning.

The carbanion solution was ca. 0.11 M and after the C.I.D.N.P. scans proved negative, the bulk of the carbanion was allowed to warm to room temperature and after 24 hrs, the deep black-red solution was transferred to a short-path length constant temperature u.v.--visible cell. The solution, presumably of 1,1,3-triphenylpropanyllithium, had an off-scale maxima ca. 490 nm* at room temperature.

C.I.D.N.P. Experiment with 5-Chloro-4,4-diphenyl-1-pentene (125-I)

In a four-neck 100-ml Morton apparatus in a dry box with nitrogen atmosphere was added 70 ml of freshly distilled THF after which 1.31 g (0.188 g-atom) of lithium wire was added at -70° followed by 1.14 g (0.008 mole) of methyl iodide. The flask was in a pentane bath which was cooled by a liquid nitrogen flow through a coil. Ten percent of the chloride solution containing 4.44 g (0.017 mole) of 5-chloro-4,4-diphenyl-1-pentene and 1.14 g (0.008 mole) of methyl iodide in 15 ml of THF was added. A pink color developed after one minute and then the remainder of the chloride solution was added over a one minute period with stirring continued at -70°. A slight green color developed which then changed to a bright red within one minute. After

*This observation agrees with the absorption of 1,1-diphenyl lithium compounds (495-496 nm) (see reference 92d).

90 min, a protonated aliquot revealed only unrearranged carbanion was present and no chloride remained. The temperature rose to -40° for a short period (< 30 min total) when the hose for the liquid nitrogen supply burst. The hose was replaced and the flask temperature again reached -70° . After 150 min total reaction time, 1-ml aliquots (ca. 15) were transferred by syringe to pre-cooled nmr tubes at -70° and the tops were sealed with epoxy cement as previously. The samples were kept cold (-78°) and taken immediately for scanning.

The tubes were removed from the cold bath and the solvent was wiped off as the tubes were placed in the A-60D probe at $+40^{\circ}$. Rapid scans (50-100 sec sweep over 500 and 100 cps range) were run intermittently (generally immediately on sample insertion and at one to five minute intervals). No inverted peaks from emission or decreased absorption were observed, although such signals could conceivably be masked by THF absorption, etc. Thus, the spectrum was not interpreted further.

The carbanion solution was ca. 0.19 M and after the C.I.D.N.P. attempt was negative, an aliquot was allowed to reach room temperature at which time the deep black-red solution was transferred to the short-path length cell. The solution, presumably of 1,1-diphenyl-4-pentenyl-lithium, had an off-scale maxima ca. 470 nm at room temperature similar to that of 1,1,3-triphenylpropanyllithium.

CHAPTER V

DISCUSSION

The discussion of this work concerning the study of 2,2-diphenyl-4-pentenyl alkali metal system can be subdivided into five sections which are as follows: (1) preliminary results, (2) catalytic effect of added reagents, (3) isotopic labeling results, (4) introduction of the concept of ion pairs, and (5) the mechanisms of migration of the phenyl and allyl moieties.

Preliminary Results on the Rearrangement of
the 2,2-Diphenyl-4-pentenyl Metal System

The initial preparation (34-I) of organolithium compound was carried out at -75° . Carbonation of the mixture after warming to 0° for 3.25 hr gave 2,2-diphenyl-5-hexenoic acid, 2, (the acid corresponding to migration of allyl). The solution aliquot taken prior to warming was protonated prematurely and comparison of neutral material from samples quenched prior to and after warming to 0° indicated different products were present. Thus, since the chloride had not completely reacted and the acid corresponding to unrearranged carbanion was not obtained prior to warming the solution, the reaction was repeated.

The second preparation (42-I) of organolithium compound was carried out just as before but was initiated at ca. -10° with 10% of the chloride ether solution being added. After reaction was realized (formation of orange-red solution) the reaction mixture was cooled to -75° and the remainder of the chloride solution was added and allowed

to react at -75° . Carbonation of aliquots before and after warming of the solution at 0° gave the acids corresponding to phenyl and allyl migration, 2-benzyl-2-phenyl-4-pentenoic acid (3) and 2,2-diphenyl-5-hexenoic acid (2), respectively. Carbonation before warming to 0° gave 15% allyl migration acid (2) and 73% of the unrearranged acid, 3,3-diphenyl-5-hexenoic acid (1). The amount of allyl migration acid was relatively high (usually 3% or less) in this instance since the reaction was initiated at ca. -10° and thus the initially formed carbanion (from 10% of the chloride) was able to undergo rearrangement prior to cooling to -75° . The acids from carbonation after warming to 0° corresponded to 3% of diphenylacetic acid (obtained from diphenylmethane impurity in the chloride), 7% of 2,2-diphenyl-4-pentenoic acid (obtained from 4,4-diphenyl-1-butene in the chloride), 85% of 2,2-diphenyl-5-hexenoic acid (2), 4% of 2-benzyl-2-phenyl-4-pentenoic acid (3, phenyl migration product), and a small trace of acid at longer retention time in reaction 42-II, which is believed to be compound X.

For comparative purposes, the chloride was reacted (49-I) with magnesium metal turnings at 25° in anhydrous ether for 6 hr. The neutral material corresponded to unrearranged hydrocarbon, 4,4-diphenyl-1-pentene, 1-RH, while the acid was in too low yield for characterization. A repeat Grignard reaction (61-I) in anhydrous ether at 35° (magnesium turnings were activated by methyl iodide) again gave unrearranged hydrocarbon but in addition gave 11.0% of assumed 2,2-diphenyl-4-hexenoic acid, 2; 80.0% of 2-benzyl-2-phenyl-4-pentenoic acid, 3; and 9.0% of compound X.

A repeat Grignard reaction (97-I) in anhydrous THF at 65°

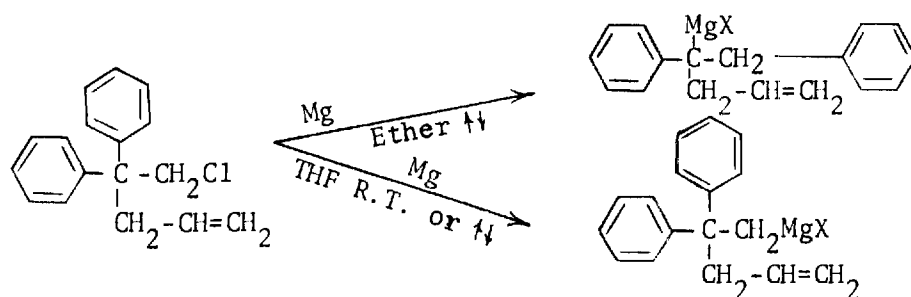
(magnesium turnings were activated by methyl iodide) was carried out and carbonated after 120 hours. The acidic material consisted of 2.0% diphenylacetic acid, 1% of 2,2-diphenyl-4-pentenoic acid, 93.0% of 3,3-diphenyl-5-hexenoic acid, 1, and 4.0% of compound X.

The above Grignard reactions were carried out with two objectives in mind: (1) to synthesize the unrearranged acid for an authentic sample via an independent method and (2) to determine whether or not allyl migration occurred as in the lithium metal reaction. The results of the Grignard reactions were more complicated than presupposed. The acidic product obtained from the diethyl ether reaction was a mixture of acids with the major acid corresponding to that of 1,2-phenyl migration according to its nmr spectrum. The acid product from the Grignard reaction in THF corresponded to that of unrearranged acid by mp and nmr spectra.^{82,83} The different results of the Grignard reactions were somewhat puzzling based on the fact it was assumed that rearrangement would have been more favorable in THF (a better solvating

82. (a) The Grignard reagent from neopentyl bromide gave, upon carbonation, the acid corresponding to 3,3-dimethylbutanoic acid; F. C. Whitmore and G. H. Fleming, J. Amer. Chem. Soc., **55**, 4161 (1933); (b) a personal communication from E. D. Hughes to C. W. Shoppee stated that the carbonation of the Grignard reagent resulting from tritylmethyl chloride gave not only the expected product, 3,3,3-triphenylpropanoic acid, but also 2,2,3-triphenylpropanoic acid (corresponding to phenyl migration). This report did not indicate the yields of the acid products obtained nor did it indicate the solvent used but based on other work by Hughes and others at this time it is reasonable to assume that the solvent was diethyl ether [C. W. Shoppee, Chem. and Ind., 759 (1954)].

83. H. E. Zimmerman and A. Zweig, J. Amer. Chem. Soc., **83**, 1196 (1961); reported the Grignard in THF from 1-chloro-2,2-diphenylpropane gave only products of unrearranged structure after one hour at reflux and 20 hours at room temperature.

solvent than diethyl ether), especially at the higher reflux temperature.⁸⁴ Since such was not the case and phenyl migration was observed in diethyl ether and not THF leads to the conclusion that the initial organomagnesium compound was apparently stabilized by solvation to such a degree that rearrangement did not take place in THF while the corresponding organomagnesium compound in ether was not stabilized sufficiently to prevent thermal rearrangement. Also worthy of note is that in the case of the magnesium metal reaction (25°-35°) the predominant migrating group was phenyl whereas with lithium metal (0°) the major migrating group was allyl. The rationale for the preferential migration of one group over another on change of solvent will be developed further in later discussion.



The reaction (99-I) of lithium with the chloride in THF at -75° and subsequent rearrangement over a relatively slow warm-up period gave, upon carbonation, the allyl migration acid (2). Kinetic analysis [99-I (suspected of being quite unreliable)] allowed the calculation

84. A. Maercker and K. Weber [*Liebigs Ann. Chem.*, **756**, 43 (1972)], however, found that $\text{CH}_2=\text{C}(\text{CH}_3)\text{CH}_2\text{CD}_2\text{MgBr}$ underwent a 1,2 vinylic migration to give $\text{CH}_2=\text{C}(\text{CH}_3)\text{CD}_2\text{CH}_2\text{MgBr}$ some 20 times faster in diethyl ether than in THF.

of the energy of activation ($\Delta E_a = 4.5$ kcal/mole), assuming first-order kinetics.

On the other hand, a more controlled reaction (118-I) at $-32^\circ \pm 3^\circ$ for the rearrangement of allyl had a half-life of $t_{1/2} = 26.7$ minutes. Another reaction (79-II) was divided and carried out at 0° and -30° with the rearrangement essentially complete at 1 and 2 hours, respectively while a third fraction was ca. half rearranged after 12 hours at -50° . Using this data plus the fact that reaction (112-II) at -50° was essentially rearranged after 96 hours, one can calculate approximate values for the rate constants, k , and in turn a plot of $\ln k$ vs $1/T$ (Figure 35) can be used to calculate values of the thermodynamic parameters.

The Arrhenius plot of Figure 35 may have curvature as the temperature of rearrangement is decreased. Whether or not such is the case is not readily apparent since the data is lacking in both the number of points and their confidence levels. However, from the slope, a "ball park" determination of the thermodynamic parameters allows one to estimate the value of ΔE_a to be ca. 14.0 kcal/mole. The corresponding values for ΔH^\ddagger and ΔS^\ddagger at -32° are 13.5 kcal/mole and -18.3 e.u., respectively. These values for ΔH^\ddagger and ΔS^\ddagger at -32° suggest that the energy barrier for rearrangement is relatively small and that the transition state is ordered; thereby suggesting an intramolecular mechanism of rearrangement.⁸⁵

85. T. L. Gilchrist and P. C. Storr, Organic Reactions and Orbital Symmetry, Cambridge University Press, Cambridge, England, 1972, p. 221.

Table 3. Data for Arrhenius Plot of Allyl Rearrangement

Temperature	k	$-\ln k$	Data Used
0° (79-II)	0.087	2.44	$x_0/x = 90/0.5$; $\Delta t = 60$ min
-32° (118-I)	0.026 0.013 0.022	3.65 4.38 3.82	corrected plot uncorrected plot $x_0/x = 98/0.5$; $\Delta t = 240$ min
(79-II)	0.043	3.15	$x_0/x = 90/0.5$; $\Delta t = 120$ min
-50° (79-II)	0.00063	7.37	$x_0/x = 89.5/57.0$; $\Delta t = 720$ min
(112-II)	0.00044	7.72	$x_0/x = 89.7/7.0$; $\Delta t = 5760$ min

$$k\Delta t = \ln x_0/x \text{ (reference 80).}$$

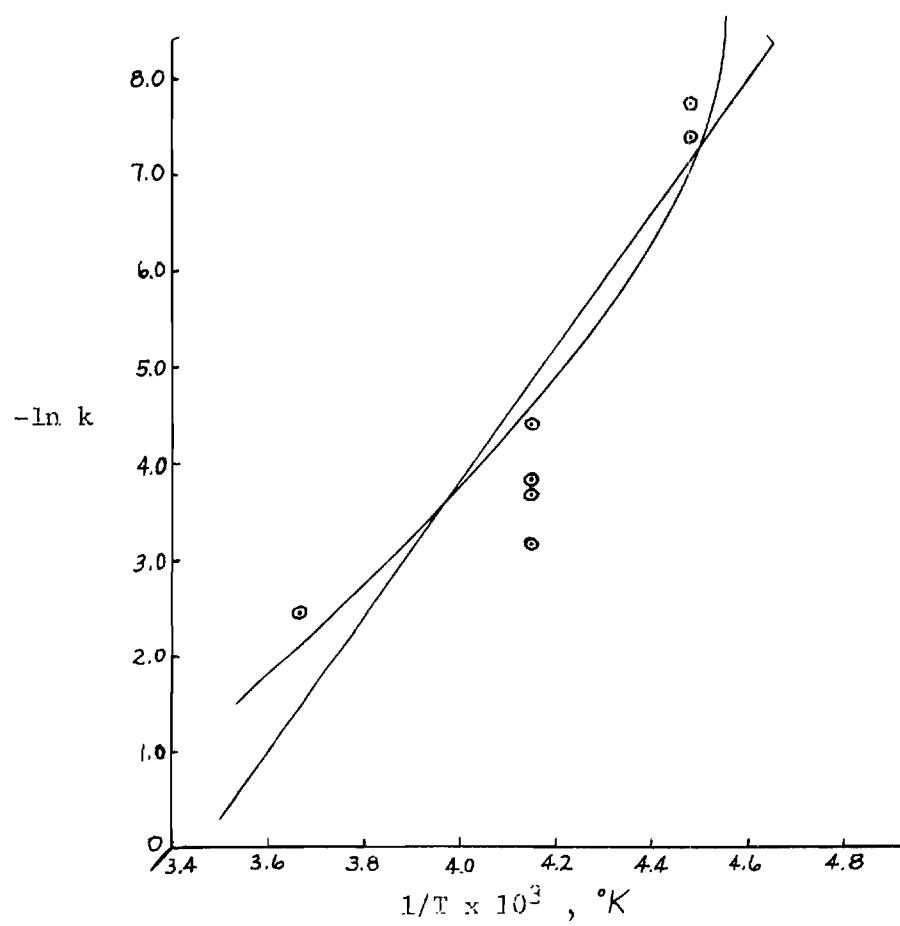


Figure 35. Arrhenius Plot of Allyl Rearrangement

Catalytic Effect of the Addition of Various Reagents
to 2,2-Diphenyl-4-pentenyl lithium

Knowing that the organolithium compound rearranged at -50° led to the consideration of (1) how other gegenions would affect the rearrangement of the carbanion and (2) whether a catalytic effect would be observed upon treating the organolithium compound with another reagent thereby altering the ratio of products or rate of rearrangement.

If the corresponding organopotassium compound could be rearranged at -75° to give different selective products of migration, the result would be of special significance to the theoretical and synthetic chemist. If allyl migration could be observed, the result would be of significance in comparing the mechanism of allylic migration of the potassium compound relative to that of the organolithium compound (i.e., labeling experiments could determine which organoalkali compound was more specific with respect to "inversion" or "retention" in the migrating allyl group). Since previous efforts to react potassium metal with various chlorides at -75° in our laboratory were not successful,* it was decided that perhaps an alternative method might be acceptable in making the organopotassium compound in the cold. Other workers in this laboratory⁸⁶ had observed a catalytic effect when potassium tert-butoxide was added to other organolithium compounds. Certain amines⁸⁷

*Dr. R. E. Williamson.

86. (a) Dr. U. J. Rhee of this laboratory; (b) E. Grovenstein, Jr. and R. E. Williamson, J. Amer. Chem. Soc., **97**, 646 (1975).

87. (a) L. Lochmann, J. Pospisil, and D. Lim, Tetrahedron Lett., 257 (1966); (b) M. Schlosser, J. Organometal. Chem., **8**, 9 (1967); (c) J. Y. Becker, S. Brenner, and J. Klein, Isr. J. Chem., **10**, 827 (1972).

as well as potassium tert-butoxide have been reported to effectively make n-butyllithium a stronger base by coordinating the lithium gegenion. Thus, it was decided that potassium tert-butoxide might prove the alternative route to the organopotassium compound (or would in any event catalyze the rearrangement).

With this hypothesis in mind, the reaction (22-II) of the organolithium compound with potassium tert-butoxide was carried out at -75° in THF. Four equivalents of the alkoxide solution per equivalent of lithium reacted were added at -75° to the initial organolithium compound at -75° . The resulting homogeneous solution was stirred for 30 minutes and then carbonated (preliminary protonated samples indicated no change in hydrocarbon product ratio in samples taken at 5 and 20 minutes after addition of alkoxide solution). The acidic product from an aliquot carbonated prior to addition of alkoxide confirmed that the major acid (98%) corresponded to unrearranged acid, 1. The acidic product from an aliquot carbonated after addition of alkoxide solution was composed of 27% allyl migration acid (2) and 62% of phenyl migration acid (3) along with 3 component acids of 11% total yield. It was in this reaction that definite evidence of phenyl migration was first observed. According to previous vpc conditions, the product of phenyl migration in the previous reactions had been minimal ($\leq 3\%$) and was eluted at the same relative retention time as the acid corresponding to unrearranged carbanion. The fact that the major product of reaction 22-II appeared at first to be unrearranged acid 1, was suspect due to the abrupt change in reaction conditions. Further analysis (mass spectrum of the crude acid mixture) indeed indicated the presence of

the acid corresponding to phenyl migration while the nmr spectrum of the crude acid mixture compared to the nmr spectrum of authentic 2-benzyl-2-phenyl-4-pentenoic acid confirmed the structure.

The search for a vpc column which would distinguish between unrearranged and phenyl migration acid products was begun. Subsequent work as well as much of the previous work was thus checked on a 15% Apiezon H column (which effected a successful separation) to determine whether or not the acid from phenyl migration and/or acid of unrearranged skeleton was present.

With the knowledge that allyl migration was the major product with lithium (-50° , 0°) and that phenyl migration was the major product with potassium tert-butoxide (-75°) it was thought that perhaps the intermediate undergoing rearrangement with alkoxide present was the organopotassium compound rather than a one to one adduct of organolithium compound with potassium tert-butoxide.⁸⁸ To check the possibility that the organopotassium compound would indeed rearrange to give such products, the reaction of the chloride with potassium metal in THF at reflux was carried out.

Reaction of the chloride with potassium metal (42-II) in THF at $+65^{\circ}$ for 10 minutes gave, upon carbonation, the acid corresponding to phenyl migration as the major product (45.8%). Allyl migration was also observed (20.3%) as well as the acid believed to be the double bond isomer of phenyl migration (11.0%) and compound X (19.3%). (It

88. (a) L. Lochmann and D. Lim, J. Organometal. Chem., 28, 153 (1971); (b) W. J. Trepke, J. A. Favre, and R. E. Sonnenfeld, J. Organometal. Chem., 55, 221 (1973).

is known that potassium tert-butoxide in THF effects a double bond shift to the more stable isomer).^{89,90} The very high relative yield of compound X was curious and could no longer be neglected; however, attempts to isolate the acid by liquid chromatography on alumina and silica gel were unsuccessful. Success was obtained in collecting the methyl ester by prepative vpc. The nmr spectrum, the mass spectrum (exact mass), and vpc relative retention time data are consistent with compound X. This acid is believed to occur by a higher energy pathway than is required for the previously known migration of allyl and/or phenyl since under the forcing experimental conditions employed, the rearrangement gave 19% rather than the typical 5% of product observed with the normal lithium system. More likely than not, it is probable that the agreement in acid ratios (allyl vs phenyl migration product) between the addition of potassium tert-butoxide to organolithium compound at -75° and the reaction of chloride with potassium metal at 65° is coincidental. Nevertheless, it is interesting to note the agreement even though the reaction conditions were so very different. This comparative result suggests but does not prove conclusively that the intermediate available for rearrangement was the same in both reactions, i.e., the organopotassium compound.

To determine further the origin of the catalytic effect on

89. (a) C. C. Price and W. H. Snyder, J. Amer. Chem. Soc., **83**, 1773 (1961); (b) D. E. Pearson and C. A. Buehler, Chem. Reviews, **74**, 45 (1974).

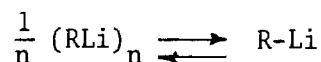
90. Transition metal catalysts have been reported to catalyze the isomerization of allyl phenyl ether to propenyl ether and a nmr spectrum of the cis and trans mixture was given by P. Golborn and F. Scheinmann, J. Chem. Soc., Perkin I, 2870 (1973).

addition of alkoxide solution to the unrearranged organolithium compound, the reaction was carried out with the addition of tert-butoxide containing other alkali metal gegenions. This study was to indicate whether the metal ion is of importance in the rearrangement.

One reaction (60-II) of the organolithium compound at -75° was carried out by adding 20 equivalents of freshly prepared lithium tert-butoxide solution at -75° . After a protonated aliquot of the reaction solution revealed that no rearrangement had occurred after one minute, the reaction mixture was allowed to stir for 40 min after which 125 ml of the solution was carbonated (carbonation II). The remainder of the solution was allowed to warm to 0° for 2 hours and then carbonated (carbonation III). The carbonated product before addition of alkoxide gave unrearranged acid, 1, as expected. Likewise, the product of carbonation II after addition of lithium tert-butoxide was also unrearranged acid, 1, while the product of carbonation III corresponded primarily to the normal allyl rearrangement product, 2. The fact that, unlike the result with potassium tert-butoxide, no rearrangement was observed on addition of lithium tert-butoxide at -75° indicates that the cation does play an important role in the rearrangement. As a matter of observation,^{84,91} it appears that addition of lithium tert-butoxide actually retards the rearrangement process rather than enhances it since 7% unrearranged acid, 1, was observed after the solution had

91. (a) D. P. Novak and T. L. Brown, J. Amer. Chem. Soc., **94**, 3793 (1972); (b) L. Lochmann, R. Lukas, and D. Lim, Collect. Czech. Chem. Commun., **37**, 569 (1972); (c) R. L. Kieft, D. P. Novak, and T. L. Brown, J. Organometal. Chem., **77**, 299 (1974).

been warmed to 0° for 2 hours. (Similar conditions without alkoxide result in complete rearrangement.) This result is rationalized by the fact that lithium compounds tend to be more associated and therefore may stabilize the original organolithium compound somewhat and thus lower the rate of rearrangement. The aggregation numbers of the organo-alkali compounds in this study are unknown but may be assumed to be tetramers in equilibration with lower aggregates in solution.⁹²

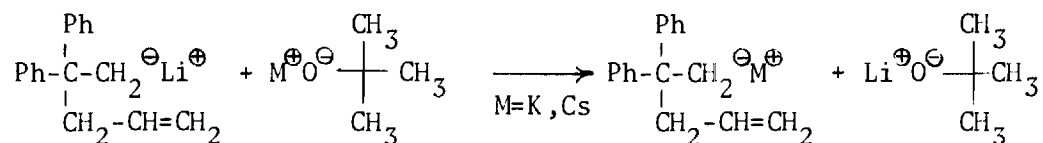


With this in mind, it was decided that more information was needed regarding the effect of added alkali alkoxides. The questions that arose were: (1) Does the order of mixing the reagents have any effect on the reaction products? (2) Could a greater amount of phenyl vs allyl rearrangement be observed by using a more ionic alkali metal alkoxide?

The reaction (92-II) of the initial organolithium compound at -75° was carried out by: (1) addition of organolithium solution at -75° to a solution of potassium tert-butoxide at -75° (inverse addition), (2) addition of potassium tert-butoxide at -75° to a solution of organolithium compound at -75°, and (3) addition of organolithium solution at -75° to a solution of cesium tert-butoxide at -75° (inverse addition). The resulting products from carbonations I, II, and III respectively

92. (a) P. D. Bartlett, C. V. Goebel, and W. P. Weber, J. Amer. Chem. Soc., 91, 7425 (1969); (b) R. Waack and M. A. Doran, J. Amer. Chem. Soc., 91, 2456 (1969); (c) R. Waack and M. A. Doran, J. Organo-metal. Chem., 29, 329 (1971).

after 10 minutes reaction time revealed that the order of mixing the reagents did not alter the acidic products or their ratios on the experimental time scale used. In addition, carbonation III from the cesium tert-butoxide addition had a greater phenyl:allyl migration ratio (75/25) than that (67/33) observed from addition of potassium tert-butoxide. This result coupled with that of the addition of lithium tert-butoxide to 2,2-diphenyl-4-pentenyllithium indicates that the rearrangement of phenyl vs allyl is favored by the larger alkali gegenion. That is, a greater percentage of phenyl as opposed to allyl migration is observed in the order Cs > K > Li. Therefore, it appears that the initial organolithium compound undergoes transmetallation and that the corresponding organoalkali compound then is available for rearrangement.



The successful catalytic effect observed by addition of potassium or cesium tert-butoxide gave the hope that other reagents might also be effective catalysts.⁹³ That such is the case is no doubt true but the following reagents (104-II) which were mixed with organolithium solution in the molar ratios specified did not effect an observable catalytic effect: RLi/lithium tetraphenylborate at -75°, 17:1; RLi/potassium

93. A. Maercker and J. D. Roberts, J. Amer. Chem. Soc., **88**, 1742 (1966).

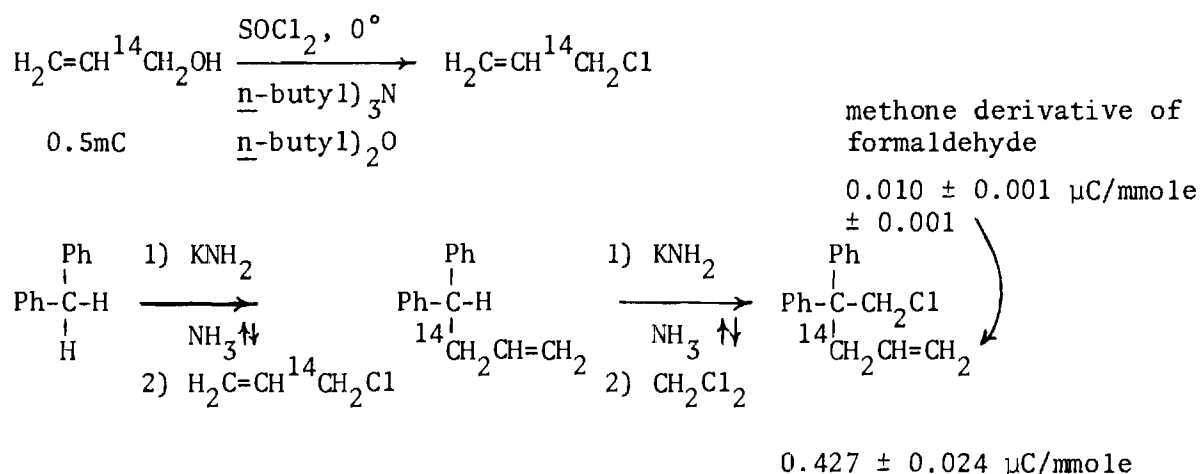
tetraphenylborate at -75° , 17:1; RLi/18-crown-6-ether at -75° , 17:1; RLi/KBr at -75° , 17:1; RLi/lithium tetraphenylborate at 0° , 17:1; and RLi/18-crown-6-ether at 0° , 17:1. These results are not reliable since it is possible that water of hydration may have quenched the tetraphenylborate salt reactions while the 18-crown-6-ether may have been decomposed at 0° . The KBr and 18-crown-6-ether reactions* at -75° were unsuccessful perhaps due to solubility problems. While the above possible problems likely could have been overcome, since there was no noticeable degree of rearrangement with any of these reagents, it was decided that further refinements in experimental conditions would not be undertaken.

Results of the Isotopic Study Concerning
the Mechanism of Allylic Rearrangement

Having established the fact that both allyl and phenyl migrate under varied reaction conditions and having established a tentative rationale for the difference or preference of migration of one group over another it was of interest to gain more knowledge concerning the migration of the allylic moiety. In order to study whether or not scrambling of the symmetric allylic termini occurred, a label was used. Several different labels could in theory and practice be used; however, since the introduction of a label may perturb the allylic system and thus does not directly yield information about the unsubstituted allylic moiety, the selection becomes more critical than one might

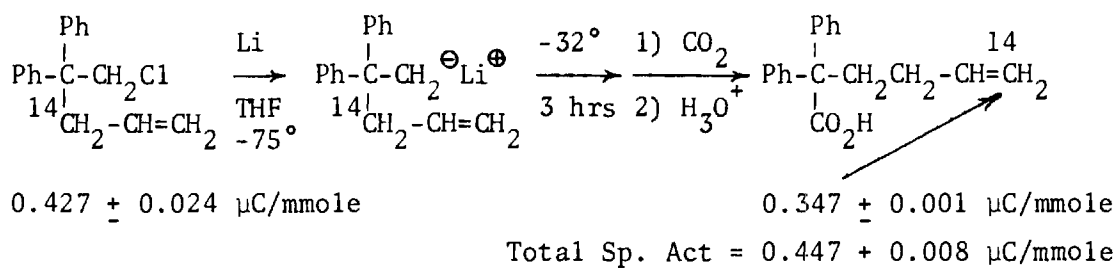
*Dr. R. E. Williamson also observed no effect on addition of 18-crown-6-ether to an analogous organolithium compound: Reference 86.

assume at first. It was decided that a ^{14}C -label would perturb the system less than the introduction of any other group or isotope (neglecting ^{13}C) while at the same time the ^{14}C radioisotope which emits a low energy beta particle is relatively safe to work with, has a long half-life, and can be measured quantitatively.⁹⁴ With these things in mind, the synthesis of 5-chloro-4,4-diphenyl-1-pentene-3- ^{14}C was carried out starting with allyl-1- ^{14}C alcohol.



The reaction (134-I) of 5-chloro-4,4-diphenyl-1-pentene-3- ^{14}C (specific activity $0.427 \pm 0.024 \mu\text{C}/\text{mmole}$) was carried out at -75° according to previous reactions of "cold" chloride. After 8.5 hours at -75° , a 100-ml aliquot of the reaction solution was carbonated and the remaining solution was then warmed to $-32^\circ \pm 2^\circ$ for 3 hours and then carbonated (carbonation II). The allyl migration acid product, 2, was isolated by column chromatography on acid-washed alumina and the radiochemical results were as follows:

94. V. F. Raaen, G. A. Ropp, and H. P. Raaen, Carbon-14, New York, NY, McGraw-Hill, 1968.



The activity was measured with a vibrating reed electrometer (VRE) and by liquid scintillation.*

The radioactivity at the terminal position was determined by ozonizing the acid methyl ester and making the methone derivative of the formaldehyde produced on reduction of the ozonide. The specific activity of the starting chloride was $0.427 \pm 0.024 \text{ } \mu\text{C/mmole}$. The recovered acid ester specific activity was $0.447 \pm 0.008 \text{ } \mu\text{C/mmole}$ while that of the terminal methylene was $0.347 \text{ } \mu\text{C/mmole}$.** This result suggests a 55% enrichment of radioactivity of the terminal carbon compared to the value of $0.224 \pm 0.017 \text{ } \mu\text{C/mmole}$ expected if the migration were completely random.** Thus, it appeared the allylic moiety did not undergo either a completely random or concerted migration; the result, therefore, suggested a possible duality of mechanism.^{35,48} It was assumed that other experiments might reveal a trend and determine

*It was necessary that an alternative method of counting be available due to the fact that prior to the completion of the radioactive counting the VRE became erratic with a large deviation in precision. However, it was shown that the two different methods of assay used gave agreeable and reproducible results in this study.

**The value of $0.347 \text{ } \mu\text{C/mmole}$ and the corresponding enrichment (55%) value are based on subsequent work and data. The real values from ozonization gave $0.282 \pm 0.001 \text{ } \mu\text{C/mmole}$ and a corresponding enrichment value of 26%. This discrepancy is due to dilution in the ozonization procedure as explained in the text following.

whether or not the allyl group does in actuality have a unique mechanism of migration, and if so, perhaps an indication as to what the mechanism or mechanisms might be.

In an attempt to determine the effect of temperature on the mechanism of allylic migration, the reaction (3-II) of 2,2-diphenyl-4-pentenyl-3- ^{14}C -lithium was carried out at 0° . After it was determined that the chloride* (sp. act. = 0.306 ± 0.002 $\mu\text{C}/\text{mmole}$) had completely reacted, a sample of the solution was carbonated. The remainder of the reaction mixture was warmed to $0^\circ \pm 2^\circ$ for 2 hours and then carbonated (carbonation II). The first carbonation acid yielded unrearranged acid, 1, of specific activity 0.290 ± 0.001 $\mu\text{C}/\text{mmole}$. The allyl migration acid product, 2, obtained from carbonation II had a total specific activity of 0.285 ± 0.003 $\mu\text{C}/\text{mmole}$ while the terminal methylene had a specific activity of 0.152 ± 0.004 $\mu\text{C}/\text{mmole}$. Unfortunately, some doubt as to the accuracy of the specific activity of the terminal methylene analysis via the ozonization procedure was raised. Therefore, to determine whether the worry was indeed valid, oxidation of the allyl migration acid by the $\text{OsO}_4\text{-HIO}_4$ method⁵⁶ with subsequent isolation and counting of the methone derivative of formaldehyde gave a terminal methylene specific activity of 0.193 ± 0.004 $\mu\text{C}/\text{mmole}$, a value of 26.8% higher than the methone derivative activity obtained by the ozonization procedure. Thus, due to the inherent fact that the specific activity

The specific activity of the chloride is ca. 6% higher than the radioactivity measurement error limits when compared to the corresponding acids 1 and 2 which were recovered and purified after reaction of the chloride. This discrepancy may be due to the fact that lower molecular weight isotopic impurities (i.e., $\text{Ph}_2\text{-CH-}^\text{CH}_2\text{CH=CH}_2$) were present.

could not in reality increase but only decrease, it was assumed that the value of specific activity obtained by the $\text{OsO}_4\text{-HIO}_4$ procedure was the more accurate. The effect of the increased temperature was that at 0° there was 34.5% enrichment* of the label at the terminal methylene. This value for the percent enrichment of the terminal methylene is not as large as that in Experiment 134-I at -32° , and it appeared that the isotopic enrichment decreased as the reaction temperature was raised. Thus, if the temperature effect was indeed real, rearrangement at an even lower temperature should yield allyl migration acid with an even greater isotopic enrichment at the terminal methylene carbon. To test this hypothesis further, it was decided that a reaction would be carried out at -50° , the lowest temperature at which rearrangement had been observed ($t_{1/2}$ of rearrangement = 12 hours).

The preparation of 2,2-diphenyl-4-pentenyl-3- ^{14}C -lithium at -75° was effected. The reaction solution was transferred to a reaction vessel at -75° and then was placed in a bath thermostatted at $-50^\circ \pm 0.5^\circ$. A 30-ml aliquot of the reaction mixture was carbonated immediately after the reaction vessel was placed in the -50° bath. The acid from this carbonation was composed of 7% allyl migration acid, 2,2-diphenyl-5-hexenoic- ^{14}C acid, 2, and 90% of unrearranged acid, 3,3-diphenyl-5-hexenoic- ^{14}C acid, 1. (A maximum of 7% allyl migration could be assumed to have occurred during the solution transfer.) With this in mind, the reaction mixture was allowed to rearrange at -50°

*A value of 6.6% enrichment was obtained by the ozonization method.

for 96.5 hours and then was carbonated (carbonation II). The allyl migration acid, 2, had a specific activity of 0.285 ± 0.002 $\mu\text{C}/\text{mmole}$ while the terminal methylene carbon ($\text{OsO}_4\text{-HIO}_4$ method) methone derivative had a specific activity of 0.237 ± 0.004 $\mu\text{C}/\text{mmole}$.* Thus, in keeping with the observed temperature effect, the allyl migration acid exhibited an even greater isotopic enrichment of 66.5%,** consistent with a more highly specific allylic migration mechanism as the temperature is decreased.

The variation in reaction temperature for the initially prepared organolithium compound from 0° to -50° showed that a definite effect was observable, i.e., that allylic migration becomes more specific as the temperature is decreased. However, even at -50° , the isotopic label, although enriched, was not 100% specific in its "inversion" to the terminal methylene position. Thus with the hope of effecting specific "inversion" of the allyl moiety, the following experiment was carried out.

A solution of the initial carbanion was prepared at -75° . After reaction of the chloride of specific activity 0.306 ± 0.002 C/mmole , a 10-ml aliquot of the reaction mixture was carbonated (the acidic product contained 96% of unrearranged acid). To the remaining reaction mixture at -75° was added 10 equivalents of a 1:1 complex of potassium tert-butoxide:18-crown-6-ether per equivalent of organolithium compound

*The specific activity determined by the O_3 method was 0.201 ± 0.002 $\mu\text{C}/\text{mmole}$.

**A value of 40.6% enrichment was obtained by the ozonization method.

present (lithium chloride is known to associate with RLi).⁹⁵ A 10-ml aliquot was immediately carbonated (carbonation II). The remainder of the reaction mixture was allowed to stir for another 30 minutes and then carbonated (carbonation III).

Carbonation II and III were identical as to acid composition and contained a significant amount 28% (2,2-diphenyl-4-pentenoic-¹⁴C acid along with 54% 2,2-diphenyl-5-hexenoic-¹⁴C acid, 2, and 9% of 2-benzyl-2-phenyl-4-pentenoic-¹⁴ acid, 3. The rationale for the large amount of the "abnormal" 2,2-diphenyl-4-pentenoic-¹⁴C acid product is that there was a small amount (3.5%) of 4,4-diphenyl-1-pentene in the starting chloride and that in the presence of the reagent potassium tert-butoxide:18-crown-6-ether complex the organolithium reagent metalated the relatively acidic hydrocarbon to yield the "abnormal" acid on carbonation.*

The acid product was purified by preparative vpc (column chromatography was unsuccessful) of the methyl esters. The allyl migration acid ester was collected and hydrolyzed to the corresponding acid. The

95. (a) Crown ethers increase the specific activity of potassium alkoxides in DMSO. M. J. Maskornick, Tetrahedron Lett., 1797 (1972); (b) J. N. Roitman and D. J. Cram, J. Amer. Chem. Soc., 93, 2231 (1971); (c) Cryptates of alkali metal salts have shown the gegenion to be in the inclusion cavity thus allowing a relatively free anion in solution as counterion. F. J. Tehan, B. L. Barnett, and J. L. Dye, J. Amer. Chem. Soc., 96, 7203 (1974).

*The starting chloride contained 3.5% of 4,4-diphenyl-1-pentene. The neutral material from carbonation I contained 13.1% and the neutral from carbonation II (should be same as III) contained 5.0%. Thus, the reasonable assumption that 13% of 4,4-diphenyl-1-pentene was available for metalation is valid and could in like manner increase to 28% relative yield.

methone derivative from the $\text{OsO}_4\text{-HIO}_4$ oxidation procedure had a specific activity of 0.303 ± 0.004 $\mu\text{C}/\text{mmole}$ for the terminal methylene carbon. The specific activity of the purified acid was attempted but was not obtained due to experimental difficulties, however, the starting chloride had a specific activity of 0.306 ± 0.002 $\mu\text{C}/\text{mmole}$. The total acid specific activity should have been identical to that of the chloride for 100% inversion and this was the case. The rearrangement went to 100% completion* under these experimental conditions and 100% of the isotopic label was found at the terminal methylene carbon in the acid product of allyl migration.

The discrepancy in the values for specific activity of the terminal methylene carbons obtained from the ozonization method as opposed to the osmium tetroxide method was a very real problem in this research. Interpretation of the conflicting data was difficult until some degree of relative agreement was established. Since the higher value(s) of specific activity was assumed to be the correct value(s) of specific activity it was shown that oxidation by the osmium tetroxide method was superior to the ozonization method. Unfortunately, it was not possible to obtain a value of the specific activity for the terminal methylene group of the allyl migration acid obtained from rearrangement at -32° but a value can be assumed by a relative comparison of data points for the other reactions on the following graph. The graph depicts the percent of "inversion" or enrichment of isotopic label at

*The rearrangement was complete in < 5 minutes after addition of the alkoxide-crown ether complex at -75° as compared to a half-life of rearrangement of 12 hours at -50° without addition of alkoxide-crown ether complex.

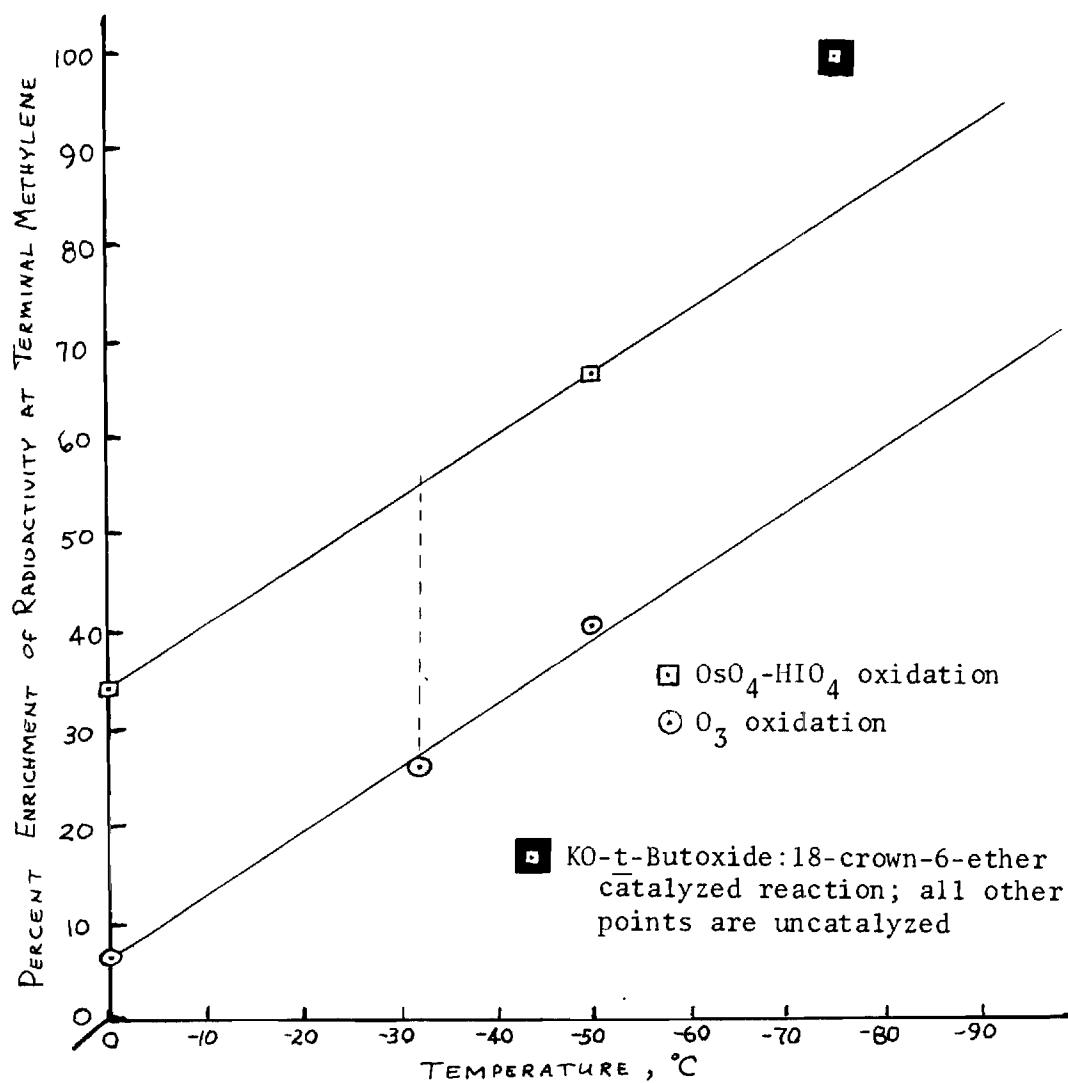


Figure 36. The Percent Enrichment of Radioactivity at the Terminal Methylene Carbon of 2,2-Diphenyl-5-hexenoic Acid vs Temperature of Rearrangement

the terminal methylene carbon vs the temperature of rearrangement for the two methods of oxidation.

It can readily be seen that the values obtained by the two oxidation methods differ quantitatively (O_3 values are ca. 25% lower than the corresponding OsO_4 - HIO_4 values) but agree qualitatively. (The slopes of the straight lines through the data points are identical.) In addition, the graph tends to support other observations* as well:

1. Extension of the solid line through the OsO_4 - HIO_4 data points suggests one would observe complete scrambling of isotopic label at $+53^\circ$ while on the other hand complete "inversion" could theoretically be realized at -112° (there is no effective rearrangement at -75°).

2. The percent enrichment of isotopic label at the terminal methylene carbon is partially linear with temperature.

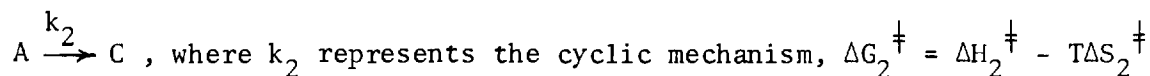
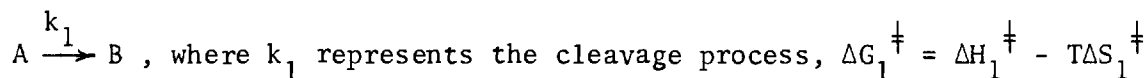
3. The data point for the terminal methylene carbon from the allyl rearrangement acid obtained at -75° on addition of alkoxide:18-crown-6-ether complex to the original organolithium compound does not fall on the OsO_4 - HIO_4 data line. This deviation is evidence for a possible catalytic effect in the mechanism of rearrangement as well as in the rate of rearrangement.

An alternative view** is that the curve in Figure 36 should theoretically be a sigmoid curve with linearity expected only for a

*An alternative view follows Figure 36.

**Dr. Erling Grovenstein, Jr.

reasonably narrow temperature range. This follows from the fact that with two competing reactions the rate constants k_1 and k_2 for the scrambling mechanism and the inversion mechanism respectively will differ and thus either reaction can be dominant at the appropriate temperature. Thus, consider the following system:



$$\frac{k_1}{k_2} = e^{-\Delta\Delta G^\ddagger/RT} = e^{-\Delta\Delta H^\ddagger/RT} e^{\Delta\Delta S^\ddagger/R}$$

$\Delta H_1^\ddagger > \Delta H_2^\ddagger$; thus, $\Delta H_1^\ddagger - \Delta H_2^\ddagger = \Delta\Delta H^\ddagger = \text{positive enthalpy difference}$

$\Delta S_1^\ddagger > \Delta S_2^\ddagger$; thus, $\Delta S_1^\ddagger - \Delta S_2^\ddagger = \Delta\Delta S^\ddagger = \text{positive entropy difference}$

Therefore, from the relationship for k_1/k_2

At higher temperature, the term $T\Delta\Delta S^\ddagger$ will dominate and hence $\Delta\Delta G^\ddagger$ will be more negative and $k_1 > k_2$.

At lower temperature, the term $\Delta\Delta H^\ddagger$ will dominate and hence $\Delta\Delta G^\ddagger$ will be more positive and $k_2 > k_1$.

The percent enrichment may be described as $\frac{k_1}{k_1 + k_2} \times 100$. At the higher temperature, the percent enrichment approaches zero while at the lower temperature, the percent enrichment approaches 100 percent. In addition, the expression for the percent enrichment may be modified by division by k_2 to and substitution for k_1/k_2 to give:

$$\% \text{ enrichment} = \frac{100}{\frac{k_1}{k_2} + 1} = \frac{100}{e^{-\Delta\Delta G^\ddagger/RT} + 1}$$

Thus, as the $\Delta\Delta H^\ddagger$ and $\Delta\Delta S^\ddagger$ terms dominate, the general curve depicting the percent enrichment vs temperature will obey a sigmoid-exponential relationship.

Considering the alternative view as to the relationship between percent enrichment vs temperature, the plot of Figure 36 may well follow the sigmoid-exponential relationship (broken line). Thus, the catalyzed rearrangement at -75° apparently involves only the rate of rearrangement, not a change in competitive mechanism as would be the case if a linear relationship were to be expected.

Having successfully effected a specific allylic "inversion," the only major question which remained unanswered was whether or not the allylic migration was intra- or intermolecular?* Since the specific "inversion" experiment indicated that allyl migration was intramolecular (with added complex at -75°) the most reasonable reaction conditions to test the feasibility of the intra- vs intermolecular allyl migration mechanism would be at the opposite extreme, i.e., conditions whereby the isotopic label approaches complete "scrambling," thus at 0° .

The "allyl incorporation" experiment to test for molecularity was carried out by preparing the "cold" organolithium compound,

*The addition product of *n*-butyllithium and 1,1-diphenylethene was observed in minor amounts when allyl migration was observed thus suggesting that some 1,1-diphenylethene was trapped (i.e., evidence for an elimination-readdition mechanism and the possibility of at least some intermolecular readdition).

2,2-diphenyl-4-pentenyllithium, at -75° , followed by addition of two molar equivalents of labeled allyl- ^{14}C -lithium at -75° which had been previously prepared by the cleavage of allyl-1- ^{14}C phenyl ether.⁹⁶ It was considered theoretically and experimentally favorable that if indeed incorporation did take place, the positive result (i.e., incorporation of radioactivity into a "cold" precursor) would be more informative than would the corresponding negative result (i.e., dilution of radioactivity of the original organolithium compound).

The reaction (134-II) of 2,2-diphenyl-4-pentenyllithium was carried out according to previous procedures. A 25-ml aliquot of the solution was carbonated and vpc analysis confirmed that the carbanion had not rearranged. Then 125 ml of freshly prepared allyl- ^{14}C -lithium at -75° was added and mixed at -75° . After addition and stirring for 20 min, a 25-ml aliquot of the reaction mixture was carbonated and revealed rearrangement still had not taken place (assumed to be the case since it was believed lithium phenoxide would not catalyze the rearrangement of allyl or phenyl since previous work had shown lithium tert-butoxide did not catalyze the rearrangement of allyl or phenyl). Finally the solution was warmed to 0° and was carbonated after 3.25 hours.

The acidic material from the last carbonation yielded allyl rearranged acid, 2, and vinylacetic acid. These acids were separated

96. The isotopic label of allyl- ^{14}C -lithium was assumed to be equilibrated at the ends of the allyl system by ionization at 0° prior to addition to the organolithium compound at -75° . P. West, J. I. Purmont, and S. V. McKinley, J. Amer. Chem. Soc., 90, 797 (1968).

and the vinylacetic acid was hydrogenated to butanoic acid. The *p*-phenylphenacyl derivative of the butanoic acid had a measured specific activity of $0.199 \pm 0.003 \mu\text{C}/\text{mmole}$ (equilibration value of allyllithium was calculated to be $0.253 \mu\text{C}/\text{mmole}$).⁹⁷ The allyl migration acid which was recovered had a specific activity of $0.026 \pm 0.001 \mu\text{C}/\text{mmole}$. The value of the specific activity of the added allyl-¹⁴C lithium was found** to be $0.295 \pm 0.006 \mu\text{C}/\text{mmole}$ by gas chromatogram analysis of the peak area corresponding to desired derivative. Thus, the value of $0.295 \mu\text{C}/\text{mmole}$ is taken as the best available value. Based on the above data, if the allyl group in the final product had been the same equilibrated activity as the allyllithium in the bulk of the solution, the activity of the final 1,1-diphenyl-4-pentenyl lithium may be calculated to have been $0.269 \mu\text{C}/\text{mmole}$.⁹⁷ That the acid product,

97. This value was calculated according to the equation $y = B \ln(A/X)$ where:

$y = 6.68$ = millimoles of carbanion to be arranged
 $B = 43.9$ = millimoles of allyllithium present initially
 $A = 0.295$ = microcurries of allyllithium present initially
 $X = \text{unknown}$ = microcurries of allyllithium expected in the bulk of the solution if complete equilibration occurred
 ($X = 0.253 \mu\text{C}/\text{mmole}$).

Thus, $(0.295 - 0.253)(43.9)/(6.86) = 0.269 \mu\text{C}/\text{mmole}$ activity expected for the allyl rearranged acid if 100% incorporation occurred. Derivation of the equation for such a system may be found in the paper by E. Grovenstein, Jr. and G. Wentworth, J. Amer. Chem. Soc., **89**, 1852 (1967).

*Nmr showed a complicated (3:1 complex) spectrum of the derivative isolated while the vpc of the isolated solid derivative (specific activity = $0.055 \pm 0.001 \mu\text{C}/\text{mmole}$) showed the (carbonation I) *p*-phenylphenacyl ester of butanoic acid to be only 18.5% of the entire area percent of the chromatogram thus suggesting a specific activity of $0.295 \mu\text{C}/\text{mmole}$ for the allyllithium initially present.

2, had a specific activity of 0.026 ± 0.001 $\mu\text{C}/\text{mmole}$ indicated that only 10% intermolecular allylic exchange took place. Therefore, it can be reasonably assumed that allylic migration occurs predominantly intramolecularly even at 0° and increasingly so as the temperature of rearrangement decreases.

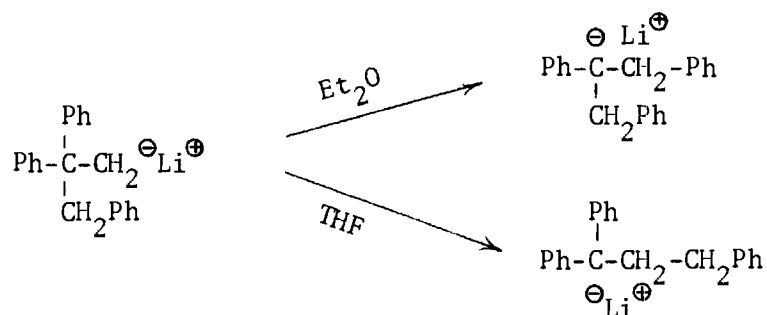
Interpretation of these isotopic tracer results for the migration of allyl suggests that only a small proportion of the migration occurs via an intermolecular mechanism. In addition, the temperature study parallels the work of Baldwin and is evidence that the allylic terminus is "selectively" inverted as the temperature of rearrangement is varied from 0° to -75° . These results suggest several possible mechanisms of rearrangement which will be discussed further under mechanisms of migration.

The Concept of Ion Pairs as a Rationale for the Migration of the Phenyl vs Allyl Moiety

Having established a rationale for the competing duality of mechanisms vs temperature involved in the migration of allyl, an obvious question still remains. What determines whether the allyl or phenyl moiety will migrate competitively and selectively from the original organolithium compound or precursor?

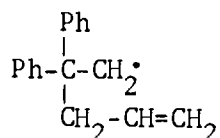
The observation that allyl migrates predominantly on warming the organolithium compound while phenyl migrates predominantly on addition of potassium or cesium tert-butoxide to the organolithium compound or on reaction of the chloride with potassium metal suggests the gegenion may be the controlling factor. But it must be remembered that the Grignard reaction of the chloride in tetrahydrofuran and diethyl ether

primarily gave products corresponding to unrearranged and phenyl migration acids respectively.* Work by Grovenstein and Williamson⁸⁶ of this laboratory in which a related concurrent study with the 2,2,3-triphenylpropyl alkali metal system was investigated showed competition between benzyl vs phenyl migration similar to this study.



The related work by Grovenstein and Williamson also exhibited a gegenion effect and the migratory aptitude of benzyl vs phenyl paralleled the reactivity of allyl vs phenyl of this study. In addition, a solvent effect⁹⁸ was also noted in which benzyl or phenyl

*An alternative explanation as to the observation that reaction of the chloride with magnesium metal gave predominantly the product of phenyl migration may be that the free radical



is present during the preparation of RMgX.

98. E. J. Panek and T. J. Rodgers, *J. Amer. Chem. Soc.*, **96**, 6921 (1974); (b) R. Laponzade, M. Mary, H. Bouas-Lourent, and P. Labandibar, *J. Organometal. Chem.*, **34**, C25 (1972); (c) M. G. Reinecke, J. F. Sebastian, H. W. Johnson, and C. Pyun, *J. Org. Chem.*, **37**, 3066 (1972).

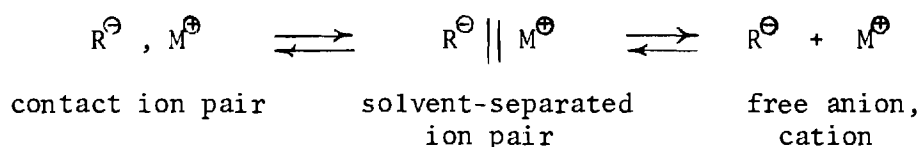
migration could be selectively and quantitatively effected in the initial organolithium compound in tetrahydrofuran or diethyl ether respectively. These facts when analyzed as a composite reveal that the effect in question is not just a gegenion effect, but more appropriately a solvent effect with an associated gegenion effect.

The addition of potassium or cesium tert-butoxide to the initial organolithium compound at -75° apparently undergoes a transmetallation to yield the respective organopotassium or -cesium compounds. Evidence for this assumption is as follows: (1) the analogous rate of rearrangement of the 2,2,3-triphenylpropyl system was shown to be dependent on the composition of the added alkoxide. (2) The acid products and ratios obtained on reaction of the corresponding chloride with potassium metal at $+65^{\circ}$ were similar to those from the addition of alkoxide to initial organolithium compound. (3) The ratio of phenyl:allyl migration product increased as the alkali metal alkoxide was added to initial organolithium compounds according to the progression $\text{Cs}^{+} > \text{K}^{+} > \text{Li}^{+}$.*

This observation suggests that in the case of phenyl migration, the gegenion is an important factor relative to the rearrangement of the anion and cannot be dismissed as an inactive or inert reagent. Furthermore, the fact that the gegenion does play an active role in the phenyl rearrangement of the anion implies the gegenion and anion are physically close and geometrically oriented. On the other hand, allyl migration apparently is favored when the gegenion and anion are not

*The solvation of alkali gegenions follows the progression $\text{Li}^{+} > \text{K}^{+} > \text{Cs}^{+}$.

physically close, i.e., increased solvation. Indeed the better the solvation⁹⁹ or complexing of the lithium gegenion, whether from the lowering of the temperature and/or from the addition of potassium tert-butoxide:18-crown-6-ether complex,¹⁰⁰ the greater the rate and specificity of allylic migration. The combination of the solvent and gegenion effects as well as the fact that two different products can be selectively obtained from the same initial organolithium compound can be satisfactorily explained by introducing the concept of ion pairs.¹⁰¹



99. The solvation of Li^+ differs for various lithium salts as the solvent is varied according to 7Li nmr. The highly coordinated ions are observed at highest chemical shifts ca. 1.5 ppm and above, while the less strongly coordinated lithium ions or those associated as aggregates are observed at lower chemical shifts. R. J. Hogan, P. A. Scherr, A. T. Weibel, and J. P. Oliver, J. Organometal. Chem., **85** 265 (1975).

100. C. J. Pederson and H. K. Frensdorff, Angew. Chem. Internat., Edit., Engl., **11**, 16 (1972).

101. "Ionic reactions in media of low dielectric constant often show a complex behavior, largely because of the variety of forms in which the reacting ionic species can exist: e.g., free ions, ion pairs, triple ions, quadrupoles, and higher aggregates. Each of the species may react with its own characteristic rate constant and stereospecificity, and frequently a rapid dynamic equilibrium may exist between two or more ionic species. Such equilibria are often strongly affected, not only by the structure of the reacting ion, but also by the type of counterion, the solvent polarity, the presence of ion-coordinating additives, and the temperature." J. Smid, Angew. Chem. Internat. Edit., Engl., **11**, 112 (1972).

The postulation¹⁰² and evidence for the existence of ions and ion pairs is becoming increasingly evident¹⁰³ as one searches the literature. However, this very useful concept is not as clear as black and white in that a continuum of solvation states may exist between the two extremes of contact (tight) ion pairs and free ions via solvent-separated (loose) ion pairs. However, based on the data regarding the migration of allyl vs phenyl moieties in this system and considering the fact that the lack of a gegenion tends to greatly facilitate a [3,2]-sigmatropic rearrangement of allyl, it is reasonable to assume that phenyl migration occurs via contact ion pairs and allyl migration via solvent-separated ion pairs.^{104*}

Phenyl migration is facilitated by solvents of low ionizing power and alkali metals of high ionizing potential with correspondingly

102. T. Hogen-Esch and J. Smid, J. Amer. Chem. Soc., **88**, 307 (1966); (b) Michael Szwarc, Ed., Ions and Ion Pairs in Organic Reactions, Wiley-Interscience, New York, NY, 1972.

103. (a) M. S. Greenburg, R. L. Bodner, and A. I. Popov, J. of Phys. Chem., **77**, 2449 (1973); (b) M. Szwarc, Accts. of Chem. Res., **2**, 87 (1969); (c) J. W. Burley and R. N. Young, J. Chem. Soc., Perkin Trans., **II**, **8**, 1006 (1972); (d) R. A. Snee, Accts. of Chem. Res., **6**, 46 (1973).

104. Contact ion pairs have been reported to be less reactive than solvent-separated ion pairs by L. L. Chan and J. Smid, J. Phys. Chem., **76**, 695 (1972); however, such a generalization is likely not always valid.

*An alternative explanation of phenyl migration may be considered to occur from an intermediate free radical generated during formation of the carbanion with potassium or cesium cation; however, this alternative does not appear to be operative when the potassium or cesium tert-butoxide procedure is used to make the corresponding organopotassium or cesium compound from the initial organolithium compound.

inverse decreasing solvating ability and is believed to occur intramolecularly; these are the conditions which would favor formation of contact ion pairs.

Allyl migration on the other hand is facilitated by solvents of high ionizing power, alkali metals of decreasing ionizing potential with a corresponding increase in solvating ability and can occur by competing mechanisms of which one mechanism is greatly favored by complete solvation of the cation to yield a "free" carbanion; these are the conditions which would favor formation of solvent-separated ion pairs.

The Mechanisms of Migration of the Phenyl
and Allyl Moieties

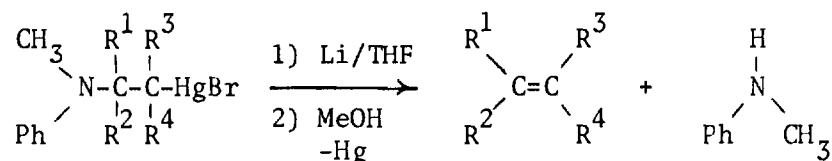
The fact that allylic scrambling takes place at the higher temperature of rearrangement but does not exchange intermolecularly to any large amount tends to support an elimination-readdition mechanism within a solvent cage. Previous work by Grovenstein⁹⁷ and Wentworth indicated the existence of such a mechanism. Continued work by Grovenstein and Williamson⁸⁶ has shown that on carbonation the product, 2,2-diphenylpropanoic acid, may be isolated (reduction of 1,1-diphenylethene)¹⁰⁵ under strongly reductive conditions.*

Supportive evidence for elimination has been the observation that β -elimination of organolithium as well as organomagnesium compounds

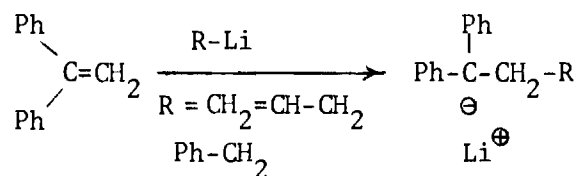
105. D. R. Weyenberg, J. Org. Chem., 30, 3236 and 4096 (1965).

*This study has also shown a minor amount of 2,2-diphenylpentanoic acid was produced on carbonation. In addition, the addition product of *n*-butyllithium to 1,1-diphenylethene was observed in minor (< 5%) amounts thus indicating that elimination does indeed occur in this system.

may occur to give olefins.¹⁰⁶



The analogy for readdition is the work of Waack and Doran concerning the addition of organolithium reagents to 1,1-diphenylethene.⁹²



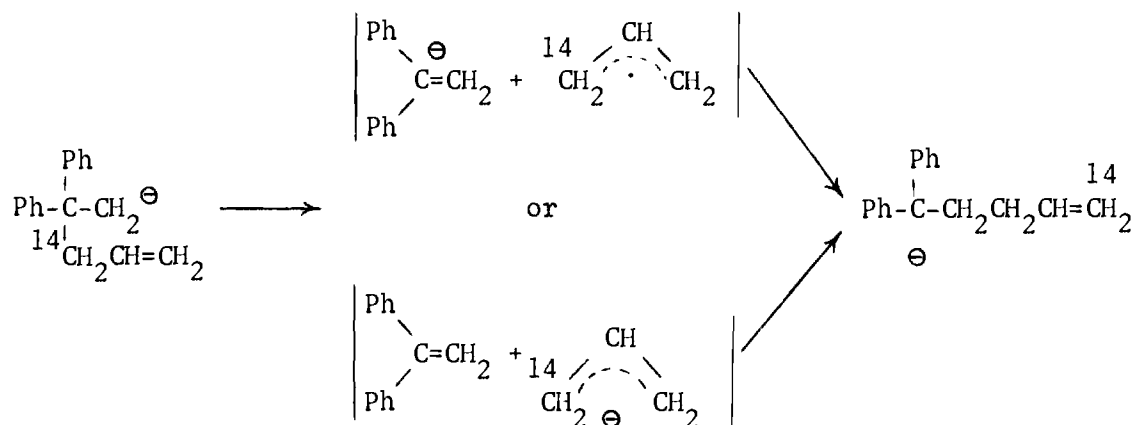
Whether the species involved are ionic or radicals is subject to controversy but it is known that the lifetime of radicals in THF is much shorter than for corresponding carbanions,¹⁰⁷ thus the evidence is consistent with the facts that the species involved are ions. The work by Baldwin⁴⁷ was followed by hydrocarbon product analysis in which radical dimerization was observed, whereas this work was predominantly concerned with acidic products and dimers of either acidic or of a hydrocarbon nature were not observed. Correspondingly, a CIDNP experiment* was negative and it would be expected that the amount of dimerization via a radical species would be minimal at best since only 10%

106. J. Barluenga, A. Ara, and G. Asensio, Synthesis, 116 (1975).

107. W. A. Pryor and R. W. Henderson, J. Amer. Chem. Soc., **92**, 7234 (1970); W. A. Pryor and J. P. Stanley, ibid., **93**, 1412 (1971); W. A. Pryor, Chem. Eng. News, 42 (June 7, 1971).

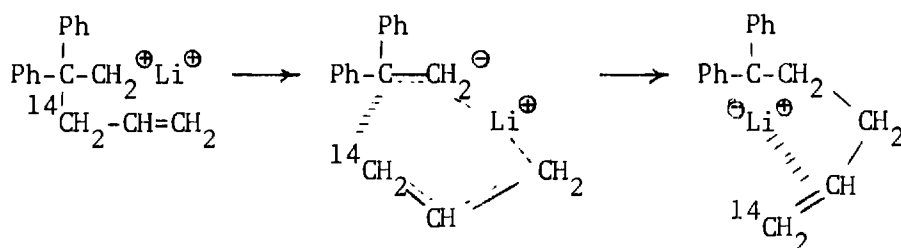
*The experimental procedure carried out on this organolithium system was given in Chapter IV.

of the reaction proceeded via an intermolecular mechanism, even at 0°.

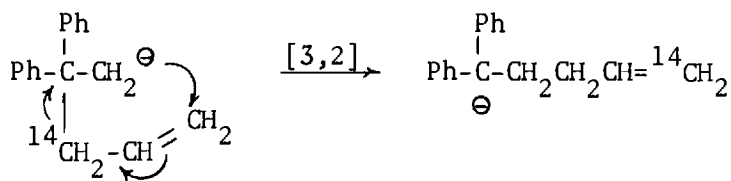


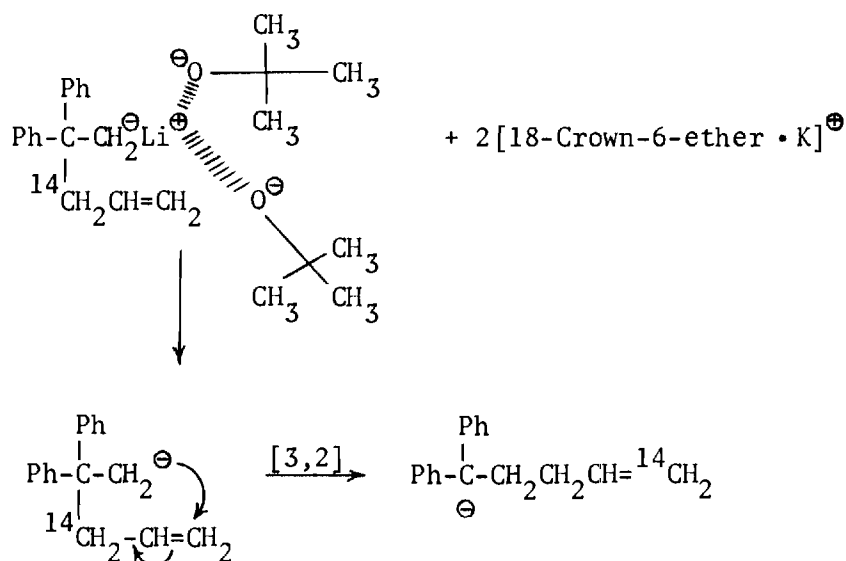
Secondly, the enrichment of the radioisotopic label at the terminal methylene of the allyl migration acid as the temperature of rearrangement is lowered suggests either a concerted [3,2]-sigmatropic rearrangement or a "memory effect" mechanism. It is known that the lithium gegenion may interact to form a π -like complex with an internal double bond of suitable geometry.¹⁰⁸ Therefore, the migration of an allyl anion may be induced and stabilized sufficiently so that the allylic terminus is preferentially coordinated with the gegenion via a cyclic six-centered transition state which then collapses to form a carbon-carbon bond in which the former allylic terminus is internal. Thus, the concept of the "memory effect" mechanism.

108. J. B. Smart, R. Hogan, P. A. Scherr, M. J. Emerson, and J. P. Oliver, J. of Organometal. Chem., **64**, 1 (1974).



Ideally, this could explain the observed temperature effect since the extremes of minimum and maximum interaction could explain the observation of "scrambling" and "inversion" respectively. However, this mechanism is not supported by the data in that the gegenion is apparently not necessary for the migration to occur. Indeed, the opposite is apparently the case since better solvation of the lithium gegenion by the potassium tert-butoxide:18-crown-6-ether complex gave 100% "inversion." If the rationale of the specific inversion was due to the greater solvation of the lithium gegenion, then it is obvious that a minimum rather than a maximum interaction of gegenion with carbanion results in specific or maximum "inversion." The only mechanism which is consistent with such an argument is that of a (six-electron) concerted [3,2]-sigmatropic rearrangement in which the terminal methylene group is enriched in radioactivity.



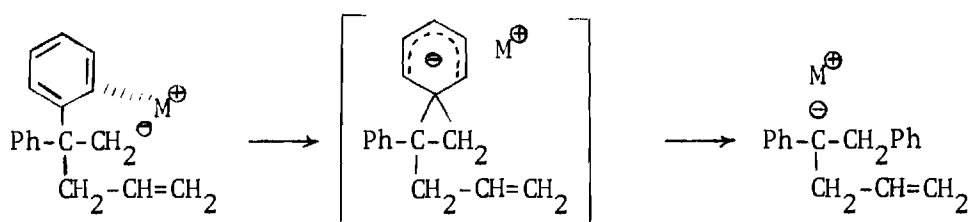


The calculation of the thermodynamic parameters for the rearrangement of allyl was discussed earlier and it is a fact that the rate of rearrangement at the temperatures and conditions studied need not follow a linear relationship.¹⁰⁹ A plausible explanation of this observation lies in the fact that the formation of solvent-separated ions from contact ion pairs is an exothermic process and has a negative entropy change.¹¹⁰ Thus, the calculated thermodynamic parameters may be a combination of conflicting relationships for the enthalpy and entropy change for both solvation and rearrangement, thus, not obvious in the overall interpretation.

109. J. W. Burley and R. N. Young, J. Chem. Soc., Perkin Trans. II, 835 (1972).

110. J. B. Grutzner, J. M. Lawlor, and L. M. Jackman, J. Amer. Chem. Soc., 94, 2306 (1972).

The transition state for the intramolecular phenyl migration⁴⁶ of the contact ion pair can be envisioned in which the gegenion is coordinated to the phenyl ring* thus facilitating the rearrangement and formation of a spiro intermediate.¹¹¹ During this process, the gegenion accompanies the anionic center such that charge separation is minimized during cyclization.



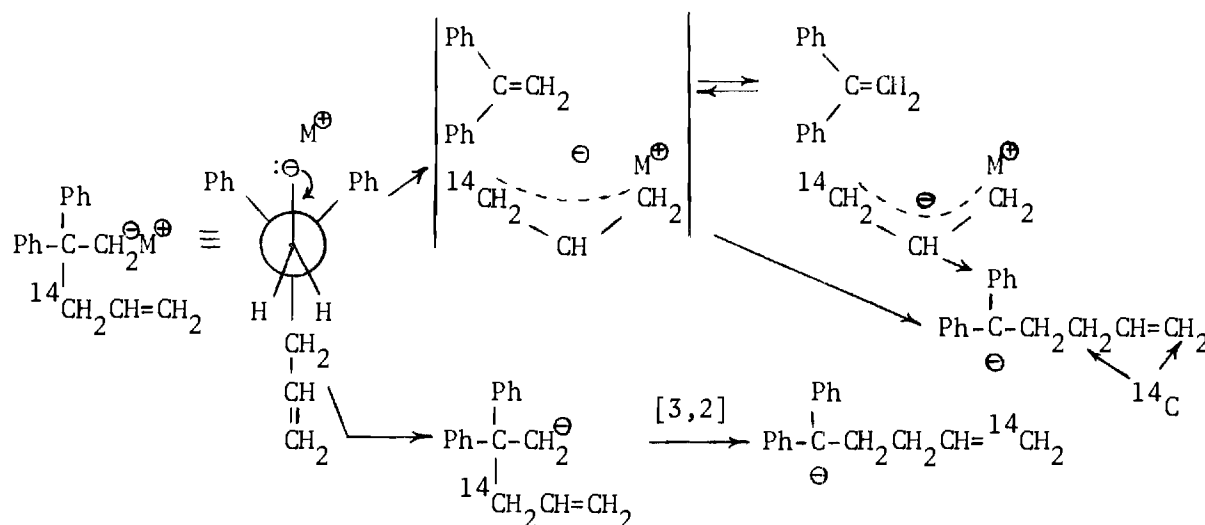
In contrast, the primary transition-state which would facilitate allyl migration, i.e., the transition-state¹¹² leading to a solvent-separated "ion pair"*** is as follows:

*The larger gegenions coordinate with phenyl as a π -complex
 $\text{Cs}^+ > \text{K}^+ > \text{Li}^+$.

111. E. Grovenstein, Jr., S. Akabori, and J. U. Rhee, J. Amer. Chem. Soc., **94**, 4734 (1972).

112. Formation of a five-membered ring adduct during the reaction of 1,1-diphenylethene with 1,3-diphenylallyl-2-carbonitrile anion may be considered a transition-state analog to the [3,2]-sigmatropic rearrangement in this study. G. Boche and D. Martens, Angew. Chem. Internat. Edit., Engl., **11**, 724 (1972).

***Solvation does not prevent electrostatic attraction, it merely reduces such attraction.



With the anion oriented in the anti-periplanar¹¹³ conformation one can envision the gegenion being solvated such that the anion is essentially "free" and thus the developing negative charge is either relieved by elimination of an allyl anion which is then free to exchange with external allyllithium and/or readd to the 1,1-diphenylethene within a solvent cage to give the more stable anion or may undergo a competing [3,2]-sigmatropic rearrangement, apparently from the same intermediate.

In conclusion, rearrangement of 2,2-diphenyl-4-pentenyl alkali metal compounds may be understood by the introduction of contact and solvent-separated ion pairs to explain the selective migration of phenyl and allyl moieties respectively. In addition, it has been shown that the migration of allyl occurs predominantly by dual mechanisms described as (1) an elimination-recombination and (2) a [3,2]-sigmatropic mechanism of which the product of the former and latter mechanisms can be selectively controlled.

113. W. H. Saunders, Jr. and A. F. Cockerill, Mechanisms of Elimination Reactions, Wiley, New York, NY, 1973, pp. 105-124.

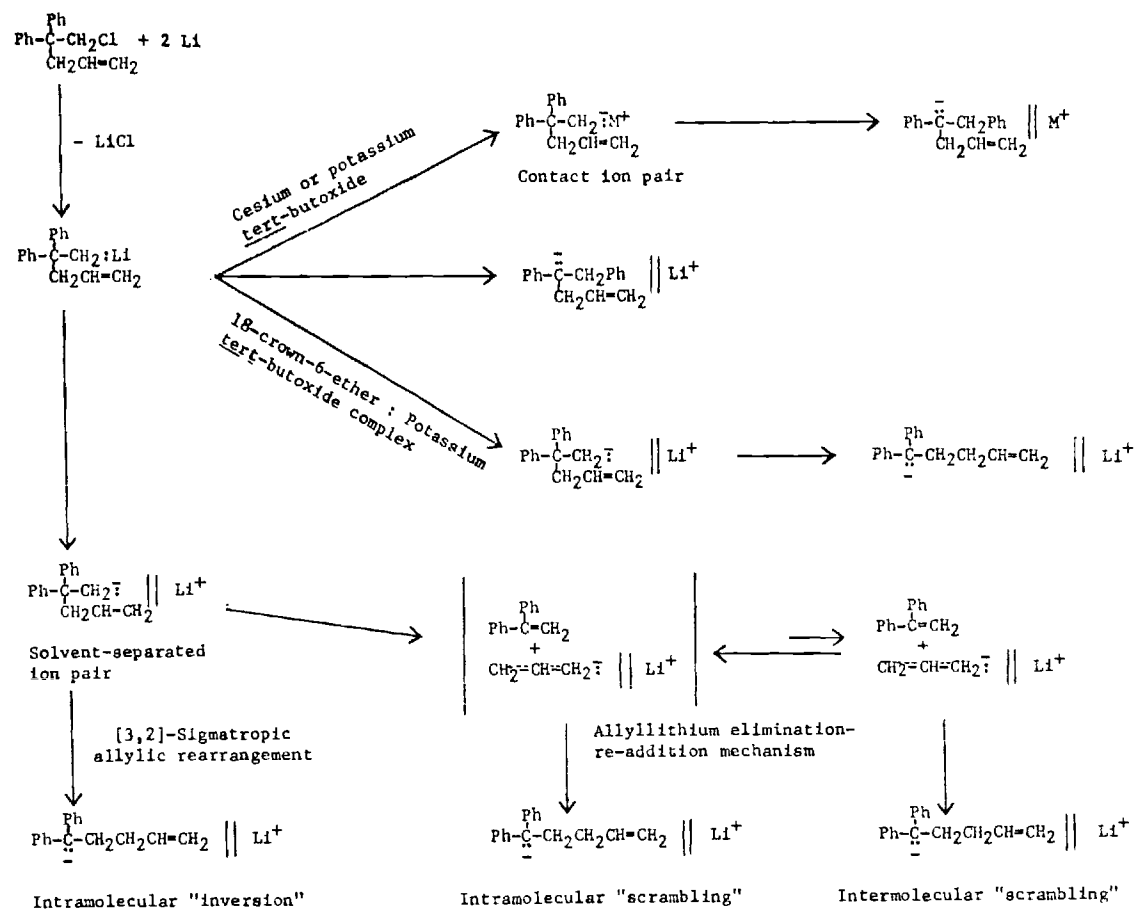


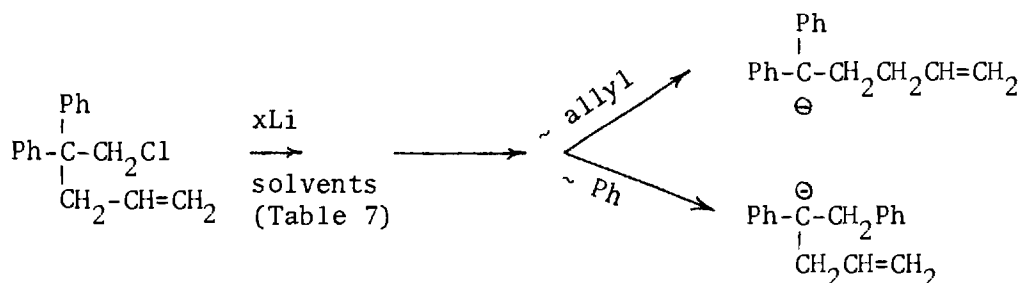
Figure 37. Overall Scheme of Rearrangement for the 2,2-Diphenyl-4-pentenyl Alkali Metal System in Tetrahydrofuran

CHAPTER VI

RECOMMENDATIONS FOR FURTHER STUDY

The work represented in this manuscript concerning the rearrangement of 2,2-diphenyl-4-pentenyl alkali metal compounds is by no means exhaustive. However, reasonable success has been realized in the understanding of the basic processes involved. As a result of the work completed, other experiments which could have been conducted, but were delayed indefinitely because of inappropriate timing, can now be considered for continued work toward the understanding of this and other carbanionic systems.

The reaction of the chloride in solvents other than tetrahydrofuran (THF) should be carried out since such a change can contribute to a better understanding as to the effect of solvent on the distribution of ion pairs in solution.



The following table of suggested solvents and the major products expected (i.e., phenyl vs allyl migration) is based on the ratio of solvent-separated vs contact ion pairs for the fluorenyllithium system as compared to THF at 25°. ¹⁰²

Table 4. Suggested Reaction Solvents with Corresponding Expected Major Products

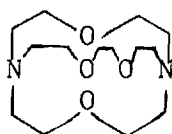
Solvent	$[F^- Li^+]/[F^-, Li^+]$	Expected Major Product
THF	4.6	Allyl
Diethylether	---	Phenyl
Dioxane	0.01	Phenyl
Tetrahydropyran	0.45	Phenyl
2,5-Dimethyltetrahydrofuran	0.02	Phenyl
2,5-Dimethoxytetrahydrofuran	0.04	Phenyl
3,3-Dimethyloxetane	1.2	Phenyl
Oxetane*	50	Allyl*
<i>o</i> -Dimethoxybenzene	50	Allyl
<i>m</i> -Dimethoxybenzene	0.01	Phenyl
1,2-Dimethoxycyclohexane	---	Phenyl
Dimethoxyethane	---	Allyl
2-(methoxymethyl)Tetrahydrofuran	50	Allyl
Hexamethylphosphoramide	50	Allyl

*The value for oxetane is for fluorenylsodium since the corresponding lithium salt was not stable in oxetane since oxetane reacts with RLi to give $R-CH_2CH_2CH_2OLi$.

While the change in solvent may lead to a greater understanding of the state of solvation, similar results may be obtained by the addition of ligands, chelates, or other coordinating reagents to the organometallic compound that has been prepared in a solvent in which the gegenion is not solvated effectively. It has been shown in this study that addition of the macrocyclic ether, 18-crown-6-ether, to the organolithium compound in THF at -75° had no effect and did not coordinate the lithium gegenion effectively. However, addition of the potassium tert-butoxide: 18-crown-6-ether complex did effectively coordinate the lithium gegenion. It is reasoned that 18-crown-6-ether did not coordinate the lithium gegenion but could coordinate the

potassium gegenion according to the order $\text{Na}^+ > \text{K}^+ > \text{Cs}^+ > \text{Li}^+$,¹¹⁴ thus allowing the free tert-butoxide to coordinate with the Li^+ .

Lehn and coworkers¹¹⁵ synthesized the chemically stable poly-oxadiazamacrobicyclic ethers and found that the "cryptates" each had a unique ability to selectively complex alkali and alkaline earth metal ions. This complexing ability depended on the metal ion and the size of the cavity of the cryptate.* It was found that the 2,1,1-bicyclic diamine was capable of coordinating the lithium gegenion effectively



2,1,1-cryptate

Inclusion cavity = 1.6 Å^o
 Li^{\oplus} ionic diameter = 1.7 Å^o

The 2,1,1-cryptate was not readily available and its synthesis would have been time-consuming, thus the idea was allowed to remain dormant. Now, however, the 2,1,1-cryptate has recently become commercially available** (albeit expensive) and should be tested immediately since it is predicted that addition of the 2,1,1-cryptate to the initial organolithium compound in THF at -75° would result in the

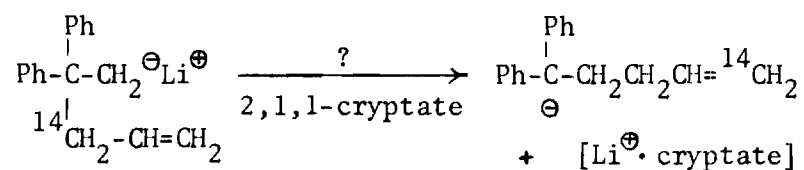
114. K. H. Wong, G. Konizer, and J. Smid, J. Amer. Chem. Soc., **92**, 666 (1970).

115. (a) B. Dietrich, J. M. Lehn, and J. P. Sauvage, Tetrahedron Lett., **34**, 2885 and 2889 (1969); (b) J. M. Lehn and J. P. Sauvage, Chem. Commun., 440 (1970).

*The stability constants, $\log K_s$, of Li^+ , Na^+ , K^+ , Rb^+ , and Cs^+ for the 2,1,1-cryptate complex in H_2O at 25° are 4.3, 2.8, <2, and <2 respectively. In addition, these stability constants are increased 3-4 units higher in methanol, ref. 116b.

**KryptofixTM 211 is available from E. M. Laboratories, Inc., associate of E. Merck, Darmstadt, Germany at sale price of \$97.50/ml.

formation of solvent-separated (i.e., "free" anion) ion pairs which would then undergo selective and quantitative "inversion" of the migrating allyl moiety.



An extension of the work with alkaline earth metals might be of significance since it was found in this work that the reaction of the starting chloride with magnesium metal in diethyl ether gave the phenyl migration product while the reaction in THF gave no rearranged products. Thus, the addition of 2,1,1-cryptate to the Grignard reagent in THF could give the allyl migration product and the versatility of the Grignard reagent could be expanded even further. As a further extension, the reaction of the chloride with other alkaline earth metals with the addition of appropriate cryptates could be of significance.

The data presented in this thesis suggests that the rearrangements are first-order in carbanion. An attempt was made to calculate ΔE_a , ΔH^\ddagger , and ΔS^\ddagger from the limited rate data but the accuracy of these calculations is certainly subject to refinement and a more detailed kinetic study should be carried out.

It is assumed that the initial 2,2-diphenyl-4-pentenyl system does not absorb in the visible region of the spectra; however, on rearrangement of allyl, the mesomerically stabilized carbanion absorbs

in the visible spectrum* ($\lambda = 4900 \text{ \AA}$, $\epsilon = 10,000\text{--}15,000$). Thus the disappearance of 2,2-diphenyl-4-pentenyllithium and/or the appearance of 1,1-diphenyl-4-pentenyllithium could be followed by recording the absorbance vs time at various temperatures in a specially designed thermostatted cell.** The rate constant and the thermodynamic functions could then be calculated for the rearrangement. In a similar manner it is assumed that the carbanion resulting from the migration of the phenyl moiety could be followed as well, but the λ_{max} would be expected to be intermediate between the unrearranged carbanion and the carbanion formed as the result of allyl migration. Although this system is thermally unstable (i.e., rearranges), it would be interesting to see whether or not the uv spectral shift resulting from the formation of solvent-separated ion pairs could be observed and whether or not the rate of rearrangement is slower or the same relative to the formation of the solvent-separated ion pairs (i.e., the formation of solvent-separated ion pairs may be rate limiting).

Even though the technique of following the rearrangement by a spectrophotometric method is advantageous with respect to recording the data, it nonetheless has its limitation. A more detailed kinetic method would be the use of the spectrophotometric technique coupled

*The solvation of contact ion pairs to form solvent-separated ion pairs is generally associated with an observed bathochromic shift in the visible and/or uv spectra of the species in question. However, a spectral shift is not necessarily a prerequisite for the formation of solvent-separated ion pairs as determined by Panek and Rogers, ref. 98.

**The special visible-uv cell was designed for use in the Cary 14 spectrophotometer (see Appendix for sketch).

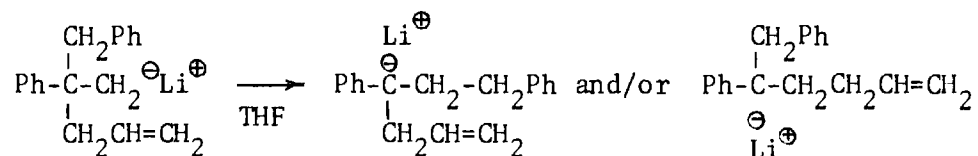
with a vpc/mass spectral analysis. The initial carbanion could be prepared and aliquots of the reaction solution quenched by D_2O at various intervals of time. Preliminary experiments have been conducted and have shown the technique to be relatively fast (samples can be taken and quenched conveniently within 30 seconds), very sensitive, and is reliable in that the data is internally consistent, yet the resulting data analysis is both qualitative and quantitative.* The ratio of RH (from solvent protonation) and RD (from D_2O quench) at ion fragments of m/e 181:182 and m/e 167:168 for the unrearranged and allyl migration protonated/deuterated carbanions respectively** gives the total relative ratio of products plus a differentiation between the respective "live" carbanions and those protonated by the solvent, etc. Thus, a combination of techniques should allow absolute kinetic and thermodynamic data to be obtained.

The work by Grovenstein and Williamson concerning benzyl migration can be compared to allyl migration in this study but the relative migratory aptitudes are so similar that nothing definitive can be stated. Thus, it would appear that the reaction of 5-chloro-2-benzyl-2-phenyl-4-pentene with lithium metal in THF would be a model

*The mass spectral fragments for the isomeric hydrocarbons corresponding to unrearranged and allyl migration carbanion were characteristic (181 and 167 respectively) and the relative intensity of the ion fragments were linear and corresponded to relative mole concentration.

**The mass spectrum of RH vs RD corresponding to the phenyl migration carbanion has not been determined but is expected to have a characteristic molecular fragment at m/e 131:132 with a possible complicating fragment at m/e 181:182.

for a direct comparison between the migratory aptitudes since the carbanions resulting from the migration of the allyl and/or benzyl moieties would be expected to be stabilized to about the same extent.



On the other hand, the carbanion resulting from phenyl migration is expected to be less stable than the initial carbanion and thus appreciable phenyl migration is not expected. With the phenyl migration limited, it is reasonable to assume that the relative migratory aptitude can be determined and that selective migration of benzyl or allyl might be observed by using other alkali metals or combinations of coordinating reagents.

Needless to say, other recommendations could be made but it would perhaps not be appropriate to continue until some of the proposed experiments have been tried and shown to be of potential value or otherwise.

APPENDIX

Table 5. Relative Retention Time of Acid Methyl Esters
on 20'--1/8"--15% Apiezon H

Compound	Relative Retention Time	Average Absolute Deviation
Phenylacetic acid	0.232	+ 0.042
Diphenylacetic acid	0.671	+ 0.040
2,2-Diphenylpropionic acid	0.708	+ 0.019
3,3-Diphenylpropionic acid	0.920	+ 0.011
2,2-Diphenyl-4-pentenoic acid	1.000	+ 0.000
2,2-Diphenyl-5-hexenoic acid	1.276	+ 0.012
2-benzyl-2-phenyl-4-pentenoic acid	1.480	+ 0.033
3,3-Diphenyl-5-hexenoic acid	1.558	+ 0.030
2,2-Diphenylheptanoic acid	1.698	+ 0.027

Table 6. Relative Retention Time of Acid Methyl Esters
on 10'--1/8"--15% Carbowax

Compound	Relative Retention Time	Average Absolute Deviation
2,2-Diphenylpropionic acid	0.753	+ 0.002
Diphenylacetic acid	0.830	+ 0.009
2,2-Diphenyl-4-pentenoic acid	1.000	+ 0.000
3,3-Diphenylpropionic acid	1.000	+ 0.000
2,2-Diphenyl-5-hexenoic acid	1.208	+ 0.009
3,3-Diphenyl-5-hexenoic acid	1.416	+ 0.012
2-benzyl-2-phenyl-4-pentenoic acid	1.416	+ 0.012

Table 7. Possible Structure of Molecular Ions and/or Ion Fragments in the Mass Spectrum of the Acids (Methyl Esters) and Hydrocarbon Products

Ions	m/e
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\ \\ \text{CO}_2\text{H}(\text{Me}) \end{array}$	282 (296)
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CO}_2\text{H}(\text{Me}) \\ \\ \text{CH}_2\text{CH}=\text{CH}_2 \end{array}$	266 (280)
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2 \\ \\ \text{CO}_2\text{H}(\text{Me}) \end{array}$	266 (280)
$\begin{array}{c} \text{CO}_2\text{H}(\text{Me}) \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{Ph} \\ \\ \text{CH}_2\text{CH}=\text{CH}_2 \end{array}$	266 (280)
$\begin{array}{l} m/e \quad (266-\text{H}_2\text{O}) = 248 \\ \quad \quad (280-\text{MeOH}) = 248 \end{array}$	
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CO}_2\text{Me} \\ + \end{array}$	239
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\ + \end{array}$	237
<p>The hydrocarbons corresponding to unrearranged carbon structure as well as those of allyl and phenyl migration have molecular ions at m/e 222.</p>	
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2^+ \\ \\ \text{CH}_2\text{CH}=\text{CH}_2 \end{array} \quad \text{or} \quad \begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}_2\text{CH}=\text{CH} \\ + \end{array}$	221

Table 7. Continued

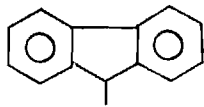
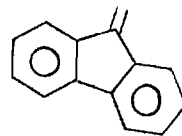
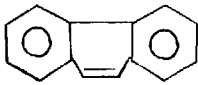
Ions	m/e
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CO}_2\text{H}(\text{Me}) \\ + \end{array}$	211 (225)
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}=\text{CH}_2 \\ + \end{array}$	207
 $^+\text{CH}_2\text{CH}=\text{CH}_2$	205
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{OMe} \\ + \end{array}$	197
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}=\text{CH}_2 \\ + \end{array}$	193
$\begin{array}{c} + \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CO}_2\text{H}(\text{Me}) \\ \\ \text{CH}_2\text{CH}=\text{CH}_2 \end{array} \quad \text{or} \quad \begin{array}{c} + \\ \\ \text{Ph}-\text{C}-\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2 \\ \\ \text{CO}_2\text{H}(\text{Me}) \end{array}$	189 (203)
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{CH}_3 \\ + \end{array}$	181
$\begin{array}{c} + \text{C}-\text{H} \\ \\ \text{Structure 1} \end{array} \quad \text{or} \quad \begin{array}{c} \text{Structure 2} \\ + \end{array}$  	177

Table 7. Continued

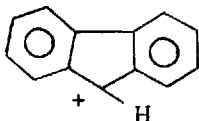
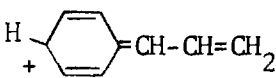
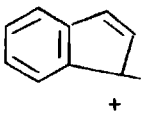
Ions	m/e
$\begin{array}{c} + \\ \text{Ph}-\text{C}-\text{CO}_2\text{H}(\text{Me}) \\ \\ \text{CH}_2\text{CH}=\text{CH}_2 \end{array}$	175 (189)
$\begin{array}{c} \text{Ph} \\ \\ \text{Ph}-\text{C}-\text{H} \\ + \end{array}$	167
	165
$\begin{array}{c} \text{Ph}-\text{CH}-\text{CH}=\text{CH}-\text{CH}=\text{CH}_2 \\ + \end{array}$	143
$\begin{array}{c} \text{Ph}-\text{C}=\text{CH}-\text{CH}=\text{CH}_2 \\ + \end{array}$	129
	117
	115
$\begin{array}{c} \text{H} \\ \\ \text{Ph}-\text{C}-\text{CH}_3 \\ + \end{array}$	105
$\begin{array}{c} \text{Ph}-\text{C}=\text{CH}_2 \\ + \end{array}$	103
$\text{Ph}-\text{CH}_2^+ \text{ or } \begin{array}{c} \text{H} \\ \\ \text{C}_6\text{H}_5 \end{array}^+$	91

Table 7. Continued


Ions	m/e
Ph+	77
+CH ₂ CH ₂ CH ₂ CH ₂ CH ₃	71
+CH ₂ CH ₂ CH=CH ₂	55
CO ₂	44
+CH ₂ CH=CH ₂	41
	39
CH ₃ OH	32
O ₂	32
CO	28
H ₂ O	18
CH ₃ ⁺	15

Table 8. Primary Acid Products and Their Sources

Compound	Source
3,3-Diphenyl-5-hexenoic acid, <u>1</u>	2,2-Diphenyl-4-pentenyl anion
2,2-Diphenyl-5-hexenoic acid, <u>2</u>	1,1-Diphenyl-4-pentenyl anion
2-Benzyl-2-phenyl-4-pentenoic acid, <u>3</u>	1-Benzyl-1-phenyl-3-butenyl anion
Compound <u>X</u>	Unknown anion

Table 9. Secondary Acid Products and Their Sources

Compound	Source
Diphenylacetic acid	Diphenylmethane metallation product
2,2-Diphenylpropionic acid	1,1-Diphenylethene reduction product
2,2-Diphenylpentenoic acid (plus possible cis and trans double bond isomer)	4,4-Diphenyl-1-butene metallation product
Vinylacetic acid	Allyl lithium
2,2-Diphenylheptanoic acid	<u>n</u> -butyllithium addition product of 1,1-diphenylethene

Table 10. Summary of ^{14}C -Distribution in the Rearrangement of
2,2-Diphenyl-4-pentenyl-3- ^{14}C -lithium

Reaction	Compound	Specific Activity $\mu\text{C}/\text{mmole}^*$
0° (3-II)	5-Chloro-4,4-diphenyl-1-pentene-3- ^{14}C	0.307 ± 0.002
	3,3-Diphenyl-5-hexenoic- ^{14}C Acid (Methone derivative of formaldehyde)	0.290 ± 0.001 (0.004 ± 0.001)
	2,2-Diphenyl-5-hexenoic- ^{14}C Acid (Methone derivative of formaldehyde)	0.285 ± 0.003 (0.193 ± 0.004)
-32° (134-I)	5-Chloro-4,4-diphenyl-1-pentene-3- ^{14}C (Methone derivative of formaldehyde)	0.427 ± 0.024 (0.427 ± 0.002)
	2,2-Diphenyl-5-hexenoic- ^{14}C Acid (Methone derivative of formaldehyde)	0.447 ± 0.008 ($0.347^{**} \quad --$)
-50° (112-II)	5-Chloro-4,4-diphenyl-1-pentene-3- ^{14}C	0.307 ± 0.002
	2,2-Diphenyl-5-hexenoic- ^{14}C Acid (Methone derivative of formaldehyde) (2,4-DNP derivative of bulk aldehyde residue)	0.285 ± 0.002 (0.237 ± 0.004) (0.045 ± 0.001)
-75° (4-III)	5-Chloro-4,4-diphenyl-1-pentene-3- ^{14}C	0.307 ± 0.002
	3,3-Diphenyl-5-hexenoic- ^{14}C Acid	0.287 ± 0.003
	2,2-Diphenyl-5-hexenoic- ^{14}C Acid (Methone derivative of formaldehyde)	(0.303 ± 0.004)
0° (134-II)	5-Chloro-4,4-diphenyl-1-pentene	"cold"
	p-phenylphenacyl- ^{14}C ester of butyric acid from initial allyllithium	0.295 ± 0.006
	p-phenylphenacyl- ^{14}C ester of butyric acid from final allyllithium	0.199 ± 0.001
	2,2-Diphenyl-5-hexenoic- ^{14}C Acid	0.026 ± 0.001

*Average values

**Value determined from graphic plots.

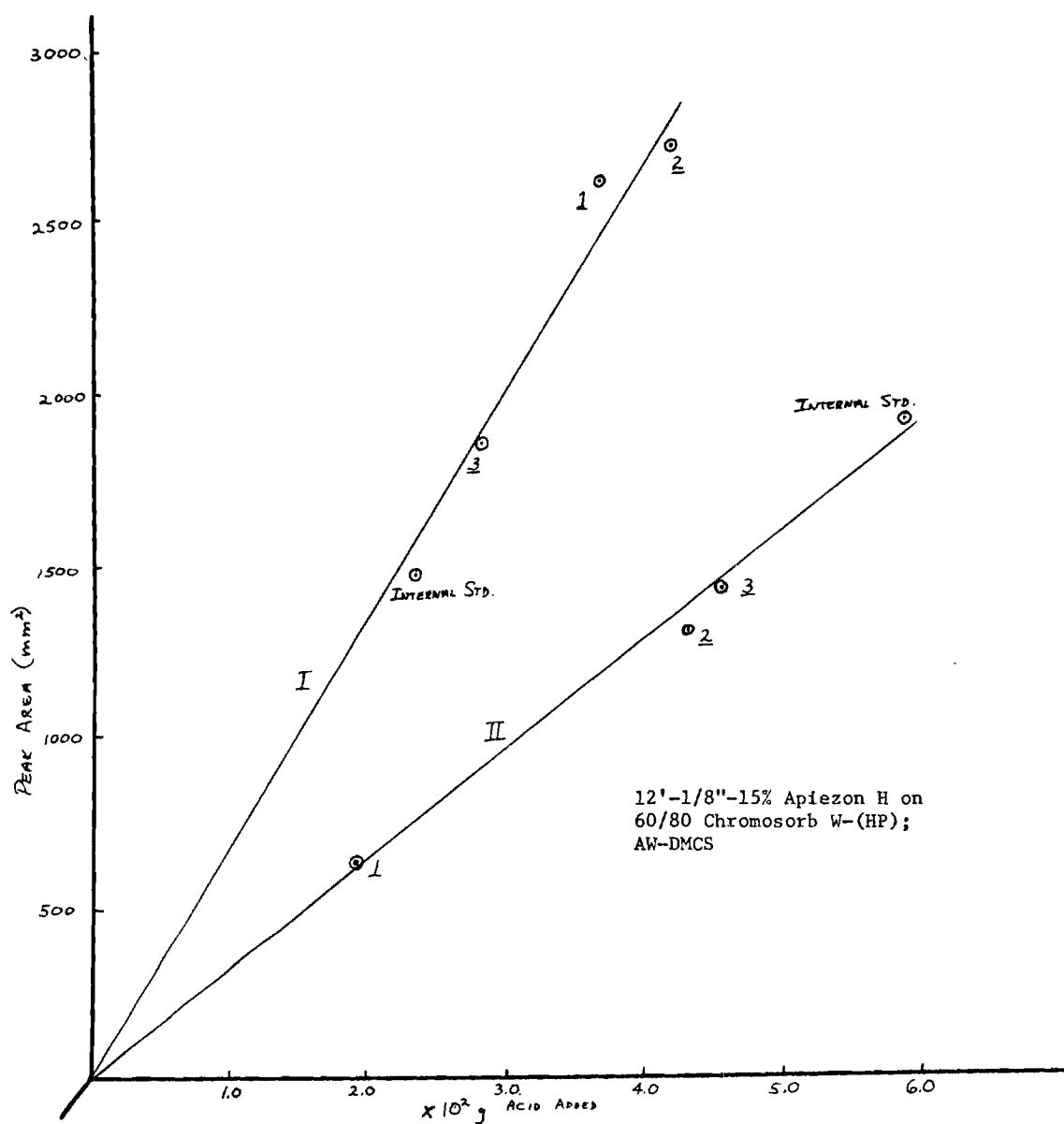


Figure 38. Correlation of Peak Area (F.I.D. Response) with Grams of Acid for Known Mixtures I and II Containing Internal Standard, 2,2-Diphenyl-4-pentenoic Acid, with Acids 1, 2, and 3. [The ordinate expresses relative rather than absolute amounts of acid ester added to the gas chromatograph for each known mixture.]

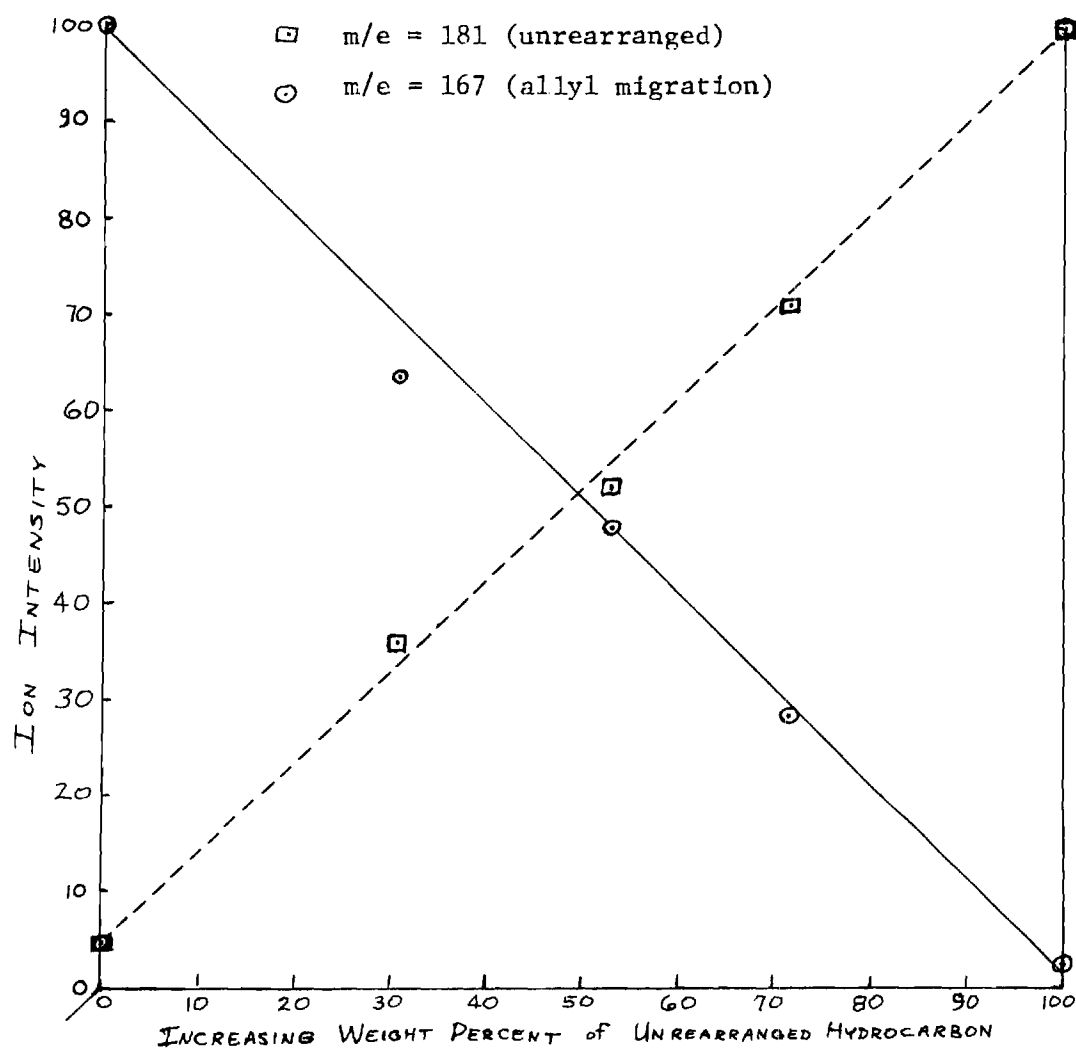
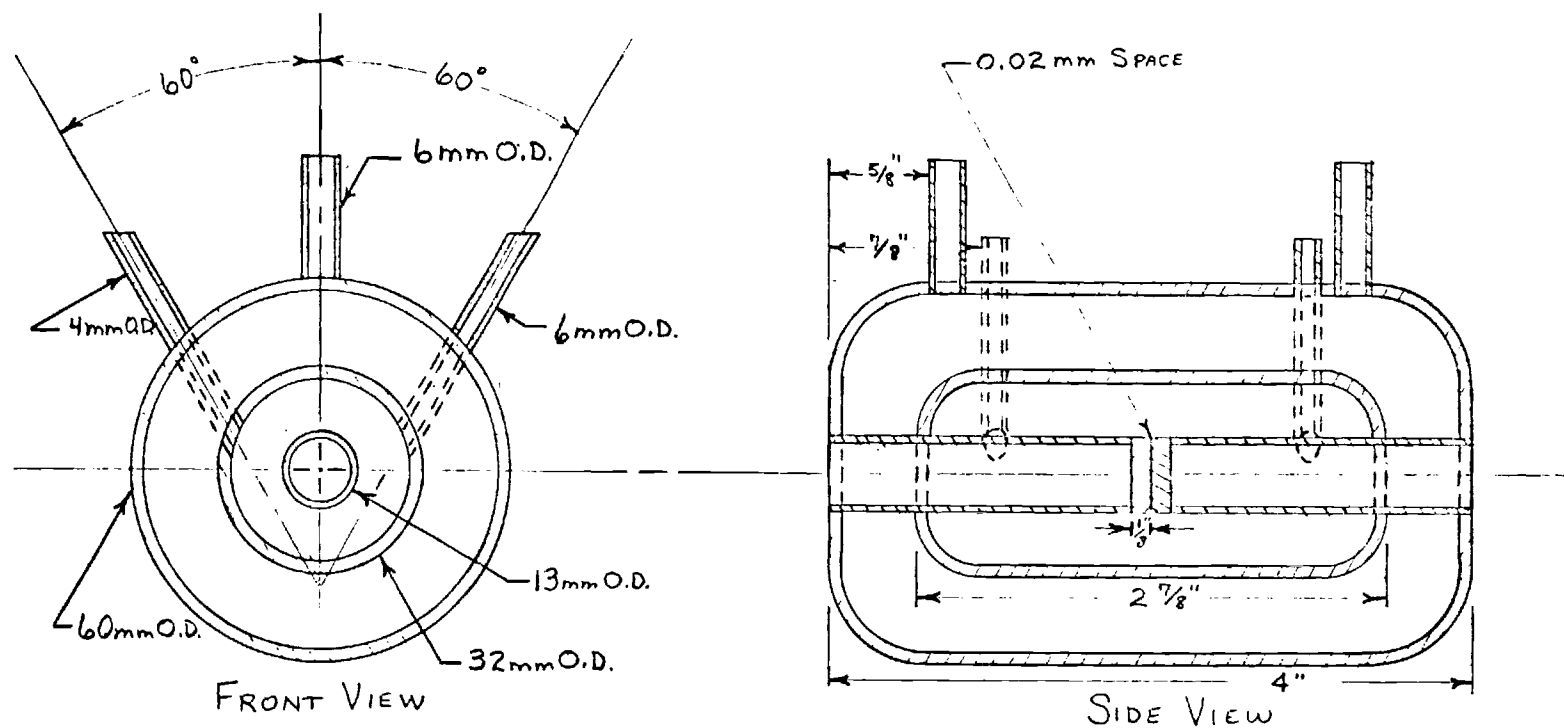


Figure 39. Calibration for Intensity of Ions 181 and 167 vs Known Weight Percent of Unrearranged and Allyl Migration Hydrocarbons, Respectively



Materials: Pyrex Glass, Standard Wall Tubing
2,4-mm Teflon Stopcocks

Figure 40. Sketch of Constant Temperature Visible Ultraviolet Spectrophotometric Cell with Short Cell Path

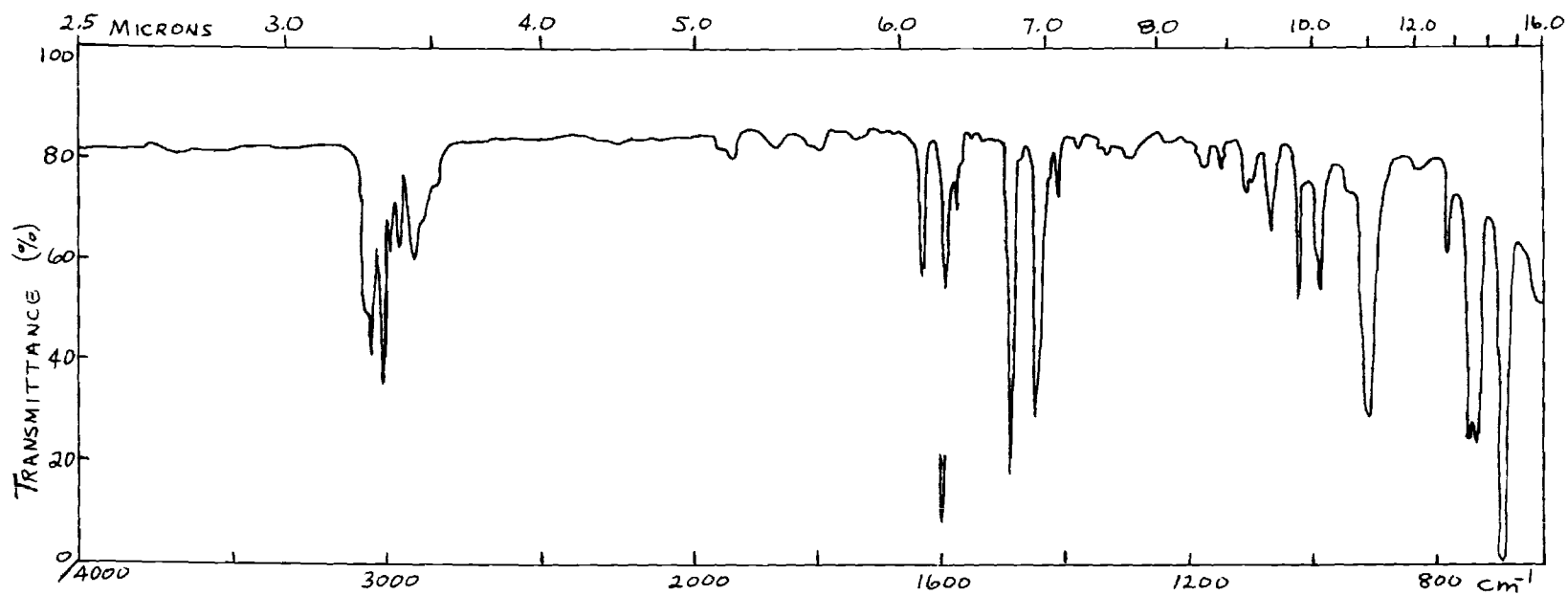


Figure 41. Infra-red Spectrum (neat) of 4,4-Diphenyl-1-butene (54-I)

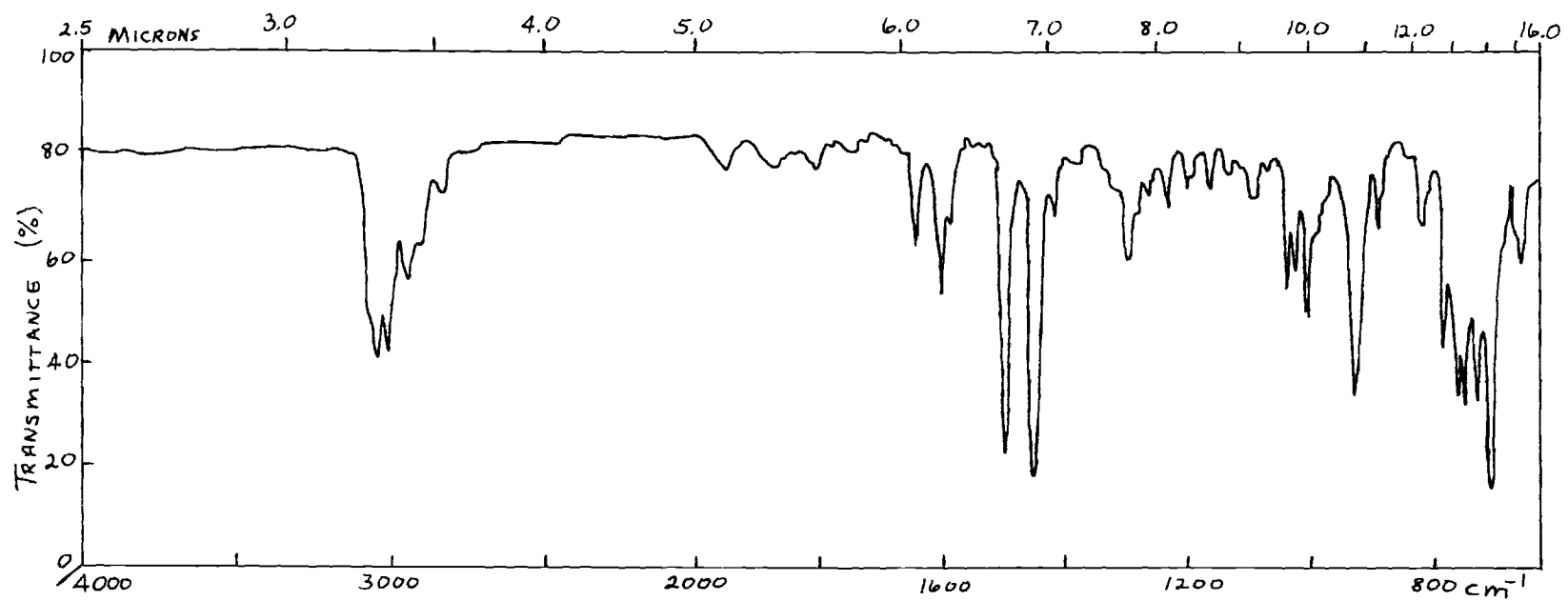


Figure 42. Infra-red Spectrum (neat) of 5-Chloro-4,4-diphenyl-1-pentene (53-II)

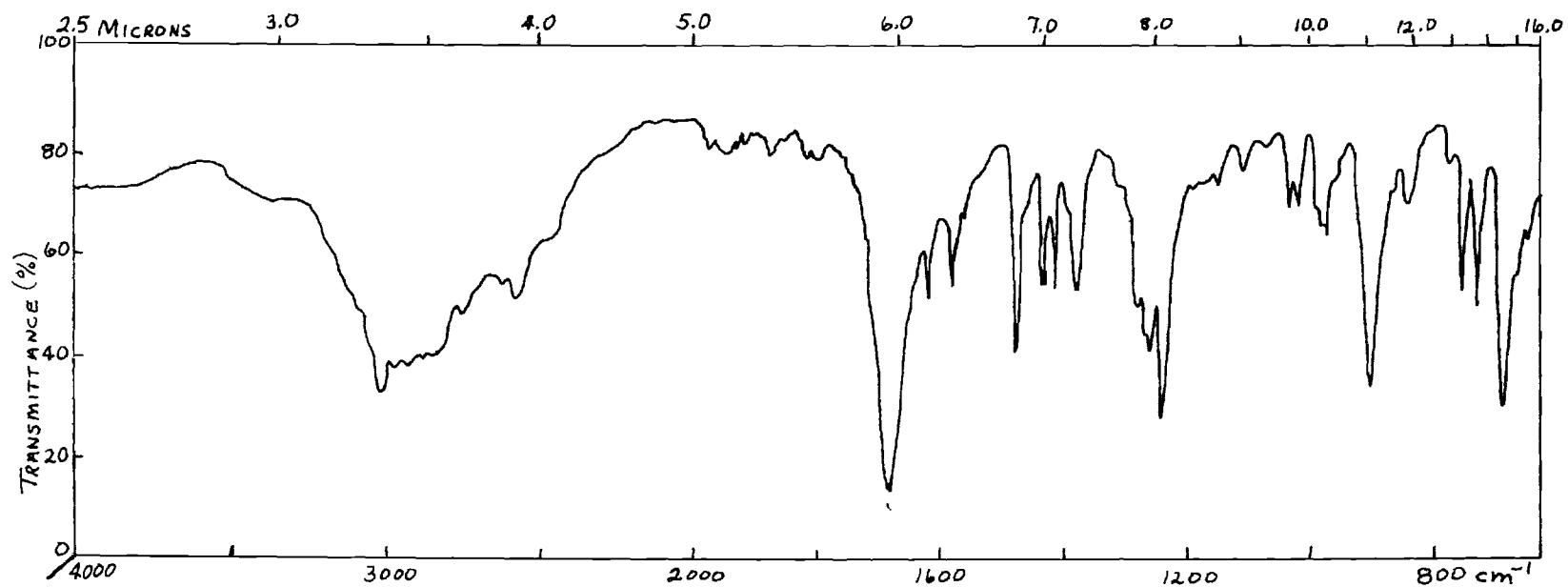


Figure 43. Infra-red Spectrum (KBr pellet) of 2,2-Diphenyl-4-pentenoic Acid (73-I)

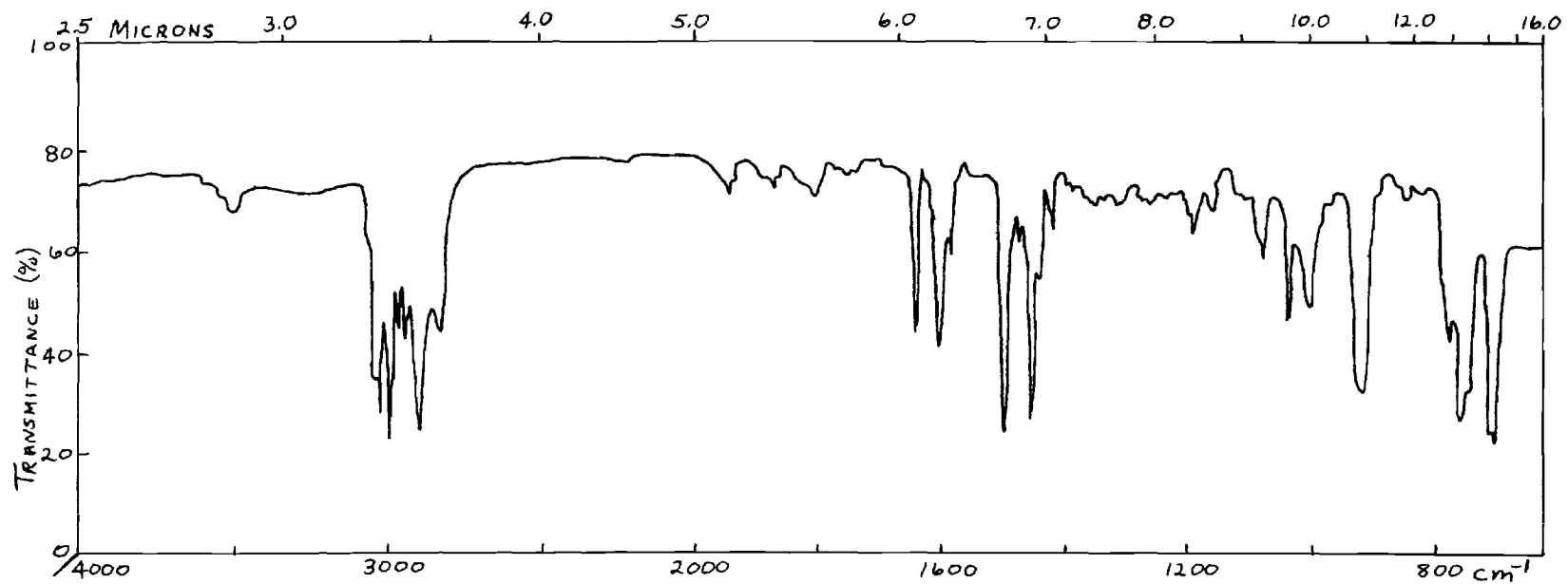


Figure 44. Infra-red Spectrum (neat) of 5,5-Diphenyl-1-pentene (91-I)

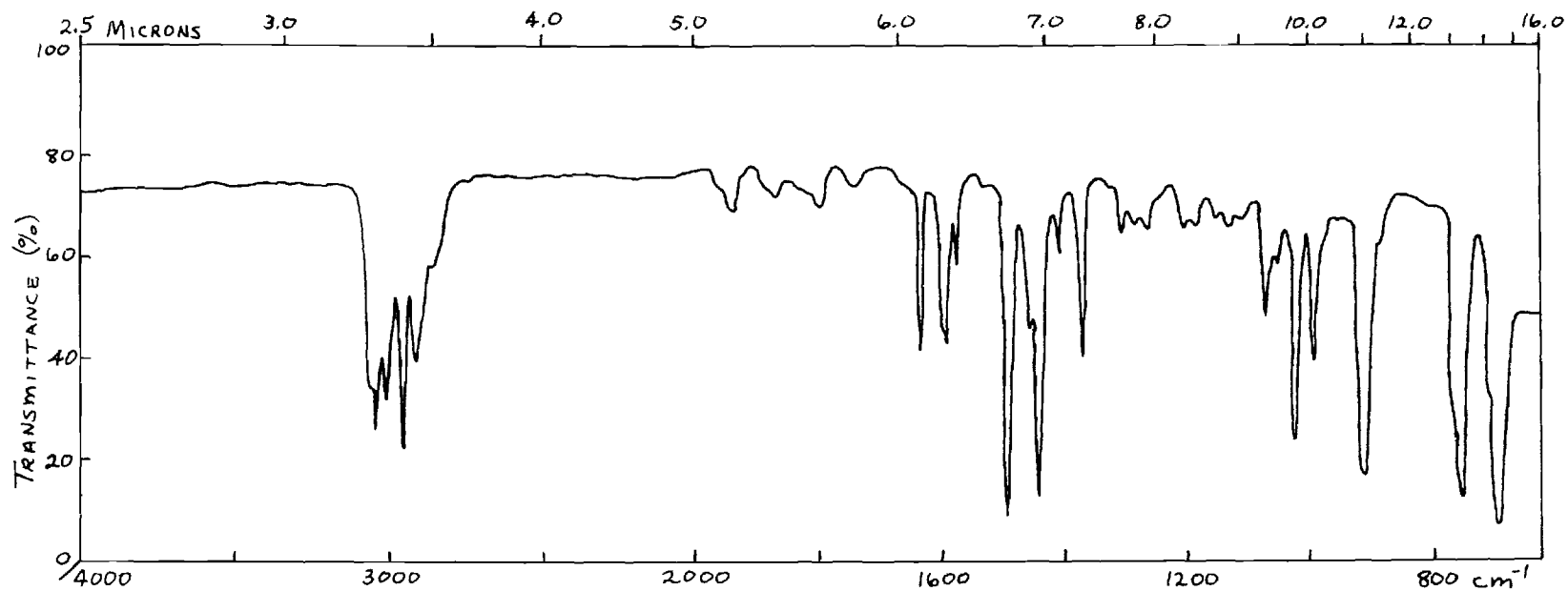


Figure 45. Infra-red Spectrum (neat) of 4,4-Diphenyl-1-pentene (110-I)

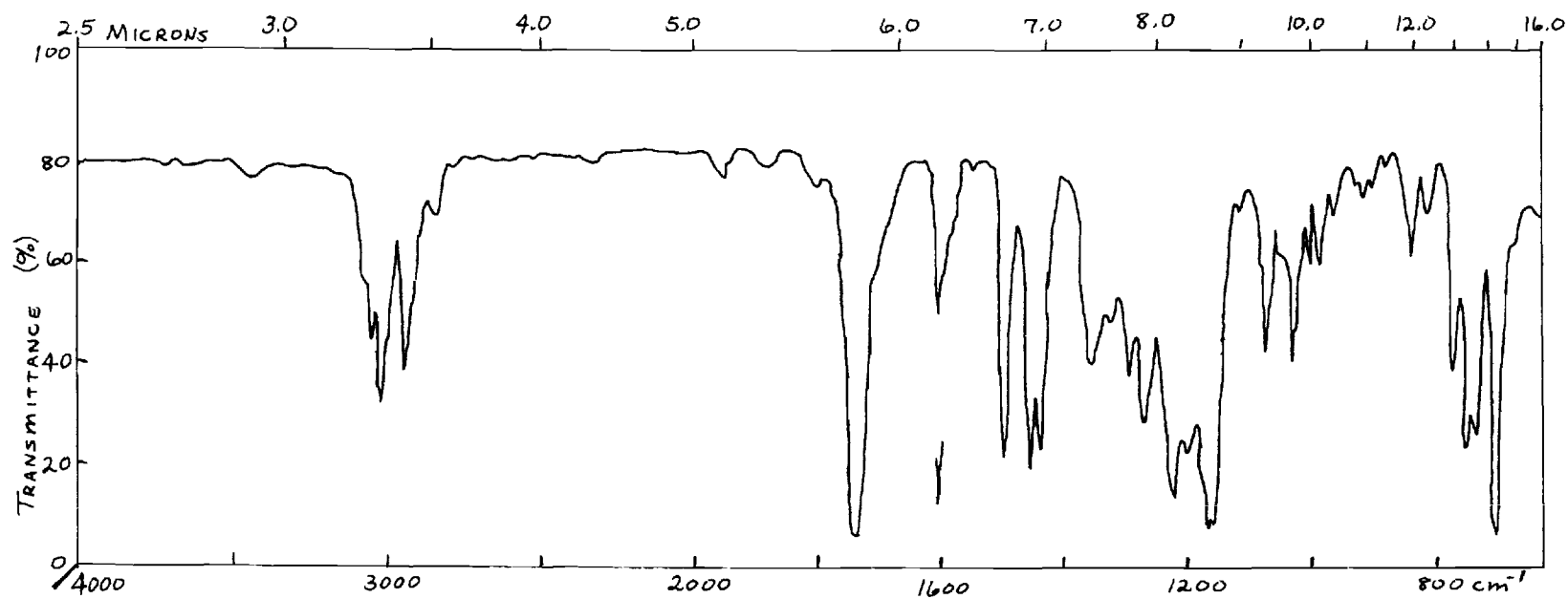


Figure 46. Infra-red Spectrum (neat) of Methyl 2,3-Diphenylpropionate (30-II)

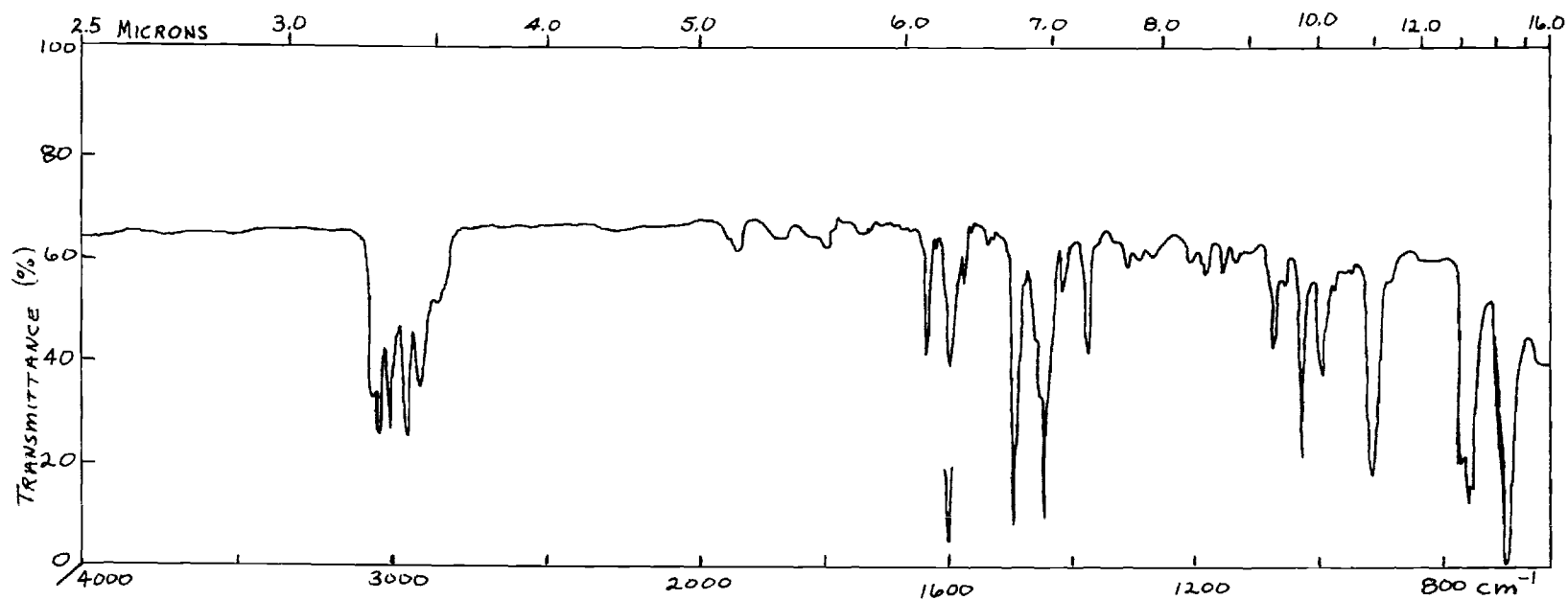


Figure 47. Infra-red Spectrum (neat) of 74°-84° Hickman Distillate of Hydrocarbon from Grignard Reaction (49-I)

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